Seasonal Bycatch Survey of the Georges Bank Scallop Fishery

Final Report

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Project Summary:

Nine trips were made to scallop access areas Closed Area I (CAI) and Closed Area II (CAII) and in open area on Georges Bank from May 2012 through March 2013. Seventy-five stations were surveyed consistently on every trip using two 4.57 meter-wide scallop dredges following standardized procedures. Scallop catch decreased significantly in both regions over the timeseries. Yellowtail catch was consistently higher on EGB than on WGB and peaked in September 2012. Sea scallop meat weight was highest from May to June 2012, and scallop spawning was semiannual. Spawning of yellowtail flounder peaked in May, while winter flounder spawning occurred in March. The CFTDD caught less flatfish bycatch while retaining a similar scallop catch as the NB style dredge. This project is a continuation of a similar survey funded through the Scallop RSA program in 2010 and 2011 (NA10NMF4540473 and NA11NMF4540027).

Trips for this project year (NA12NMF4540034):

F/V Zibet	May 04 – 11, 2012
F/V Kayla Rose	June 20 – 26, 2012
F/V Anticipation	August 06 – 14, 2012
F/V Liberty	September 25 – October 01, 2012
F/V Celtic	September 25 – October 01, 2012
F/V Horizon	November 3 – 12, 2012 (Nov. 3-7; Nov. 9-12)
F/V Thor	December 04 – 16, 2012 (Dec. 04-07; Dec. 11-16)
F/V Polaris	January 28 – February 03, 2013
F/V Vanquish	March 15 – 22, 2013 (Mar. 15-20; Mar. 21-23)

INTRODUCTION

The sea scallop, *Placopecten magellanicus*, is one of the most economically valuable marine species in the northeastern United States and supports the most valuable wild scallop fishery in the world (Hart and Chute, 2004). The stock has been rebuilt and no overfishing is occurring. However, the scallop fishery is now allocated a bycatch cap of yellowtail flounder (*Limanda ferruginea*) and if it is exceeded scallop harvest will be restricted. Furthermore, it is possible that if yellowtail stocks remain at low levels, the scallop fishery could be directly limited to further reduce bycatch. Management measures to constrain the harvest of sea scallops have resulted in the loss of millions of dollars to the communities of the Northeast and Mid-Atlantic regions of the United States.

Under Amendment 10 to the Sea Scallop Fishery Management Plan (FMP) the scallop resource is harvested through rotational area-based management to allow for identification and protection of juvenile scallops (NEFMC, 2004a). Despite the success of this program for scallop harvest, the spatial and temporal influences on bycatch of groundfish species has not been quantified. Currently, the opening of the three closed areas on Georges Bank may coincide with migration of yellowtail into these areas. Restrictions on the timing of scallop harvest in these areas may result in high bycatch of yellowtail flounder and reduced meat yield of scallops.

Framework 16/39 to the Scallop and Groundfish FMPs defined the access season for scallop vessels from June 15 to January 31 (NEFMC, 2004b). According to the rationale in the joint Framework, the Council made this decision based on unknown but potential risks to spawning groundfish and unknown but potential higher bycatch rates during the spring "when bycatch could not be predicted based on existing data." The document pointed out as part of the rationale that data may become available from future research. The scallop industry, according to the document, supported year round access to reduce the effect of concentrating landings in a short timeframe, improve meat yields by avoiding harvest during scallop spawning in the fall, and address safety and weather concerns during the fall and winter seasons.

A report was prepared for the NEFMC (January 27, 2004) by the Ad Hoc Working Group examining ways to limit incidental catches of yellowtail in scallop access programs. The Working Group noted that "neither the Groundfish Oversight Committee nor the Scallop Oversight Committee had recommended restricting the seasons of access" to the three groundfish closures on Georges Bank. Furthermore, the report indicated that "all of the available data on bycatch in scallop dredges in those areas came from the period mid-June to January." The report informed the Council that "bycatch rates in the late winter and through the spring could be <u>very</u> different from the available estimates based on summer and fall data."

The reauthorized Magnuson-Stevens Act (U.S. DOC, 2007) established new requirements to end and prevent overfishing through the implementation of ACLs and Accountability Measures (Section 303(a)(15)) for all stocks and stock areas. For the US sea scallop fishery, these requirements apply to the target stock, Atlantic sea scallops, as well as to non-target species, including three yellowtail stocks (Georges Bank, Cape Cod/Gulf of Maine and Southern New England/Mid Atlantic).

Seasonal data on scallop meat yield and groundfish bycatch rates are lacking. Spatial and temporal variation in scallop meat yield has been observed on Georges Bank in relation to depth, flow velocity, and water temperature (Sarro and Stokesbury, 2009). Also, variations in yellowtail bycatch rates have been noted in open and closed areas on Georges Bank through observer data (Bachman, 2009). However, there is currently limited information pertaining to meat yield and bycatch in closed areas from February through mid-June due to the absence of fishing during this time period. This survey fulfills the need to consistently monitor different regions of Georges Bank in order to gain a better understanding of seasonal variability in meat yield and bycatch rates.

It is also important to monitor changes in distribution and reproductive patterns of bycatch species given the adaptation of many fish stocks to warmer water temperatures and changing circulation patterns (Nye et al. 2009). The results of this survey can help to inform management of scallop and groundfish stocks by providing seasonal distribution and reproductive data.

The focus of this project is to define shell height/meat weight relationships and bycatch rates on a finer spatial and temporal scale. We did this by collecting general data on bycatch rates of all major bycatch species in relation to meat weight as well as by calculating area swept biomass for yellowtail flounder in the study areas. Two standardized dredge designs were also compared to test whether fish bycatch could be reduced via gear engineering.

The bycatch survey has been modified and adapted throughout the past three years to address new research areas. One new effort in 2012 focused on the presence of variable sized nodules on the liver, heart and serosal surfaces of yellowtail flounder. Sampling protocol was established in 2012 to identify the disease and better understand the prevalence, distribution, and effects these nodules may have on a vulnerable yellowtail population. Yellowtail and winter flounder reproductive maturity data collection continued in order to potentially gain a better understanding of the biological factors driving migration patterns.

We continued our study of sea scallop reproduction. Although Georges Bank supports the largest wild scallop fishery in the world (Caddy, 1989), little is known about spawning patterns in this region. Georges Bank scallops are generally considered fall spawners. However, there is some evidence of spring spawning in this area (DiBacco et al., 1995; Almeida et al., 1994). Semiannual spawning would be an important distinction as current management is based on annual spawning (DiBacco et al., 1995) and semiannual spawning could alter yield per recruit estimates.

In the energetics portion of this study, proximate analysis was performed on scallop meat tissue to examine spatial and temporal variability in moisture, protein, lipid, ash and carbohydrate content. In 1992, the USA Food and Drug Administration (FDA) determined that scallops with a total moisture content of 80% or less, if not subjected to processing conditions utilizing excessive water and/or phosphate treatment, could be labeled simply as scallops. Scallop products whose total moisture analysis demonstrated a percentage of 80.0 % to 84.0% would have to be labeled " X % Water Added Scallop Product." The regulation of moisture content in scallop meat is due to a concern that phosphates could be misused to retain "added water," increasing the size and weight and thus, unfairly, the value of the scallop meat. The calculation of total moisture to protein ratio has been introduced as a potentially more accurate representation of natural moisture content in scallop meat (Codex, 2003). In sea scallops the moisture:protein ratio is considered to be 4.0 to 4.9:1.0 (Lampilla, 1993). Thus, a ratio of about 5:1 would indicate a product with added water. This project will provide seasonal and spatial data on the natural variability in scallop moisture and protein values.

A study of stable isotope deposition in scallop shells provided data about environmental influences on growth. Scallops have a sequential skeletal deposition, which provides a good medium for archiving environmental and physiological changes in growth. Oxygen isotopes are thermodynamically sensitive and the fractionation of $^{18}O/^{16}O$ ($\delta^{18}O$) is mediated by the reaction temperature (Tan et al., 1988; Krantz et al., 1984). Numerous studies have shown that the sequential $\delta^{18}O$ signature in bivalve shell carbonate fluctuates with water temperature (Goewert and Surge, 2008; Owen et al., 2002; Jones and Quitmyer, 1996; Tan et al., 1988; Krantz et al., 1984). In the summer, at warmer sea water temperatures fewer of the heavier ^{18}O isotopes are incorporated into the shell carbonate resulting in a "lighter or depleted" isotope value. In the winter, the opposite is true and more of the heavier isotope is deposited in the shell producing a "heavier or enriched" isotope signature. Thus, the $\delta^{18}O$ signature in scallop shells can provide an estimate of seasonal growth and age (Jones and Quitmyer, 1996; Krantz et al., 1984). As the carbonate $\delta^{18}O$ signature reflects the water temperature when the shell was deposited, the $\delta^{18}O$ value from the umbo can indicate if a scallop originated from a spring or fall spawning event.

Studies suggest that scallop meat weight fluctuates annually (Sarro and Stokesbury, 2009; Penney and McKenzie, 1996). Meat weight decreases during gametogenesis (Sarro and Stokesbury 2009), when energy reserves in the form of glycogen and lipids are reallocated from the adductor muscle to the gonad (Gould et al., 1988; MacDonald and Thompson, 1986; Robinson et al., 1981). The timing and the extent of this energy transfer is important for scallop growth and recruitment. Thus, seasonal glycogen levels may be an indicator of scallop condition and reproductive potential.

In addition to scallop energetics and reproduction data, sea scallop shell height and meat weight data were collected on all cruises during the course of this study. The purpose of these collections was to estimate area and time specific relationships in an effort to document the annual variation in scallop meat weight. These estimates will provide a relative measure of scallop yield and comparing these findings to the relative catch of major bycatch species will help to achieve an optimized harvest strategy.

METHODS

The project consisted of nine research trips aboard commercial scallop vessels. Each trip was approximately five days of sampling, with two days for steaming to and from the sampling grounds. A grid survey design was used in which the same sites were sampled every six weeks. In order to ensure that the same stations were consistently sampled, we designated each station as either "core" or "bonus." A valid tow was required at core stations on every trip; if a tow was invalid, then the station was retowed. Bonus stations were sampled on each trip, but were not retowed if a tow was invalid. Thirty-five total stations were designated in CAI (26 core stations, 9 bonus stations) and were spaced 5.39 km (2.9 nm) apart longitudinally and 7.18 km (3.9 nm) apart latitudinally (Figure 1). Forty-six stations were established within CAII and south of CAII in open area (37 core, 9 bonus) and were spaced 8.55 km (4.6 nm) apart longitudinally and 11.12 km (6.0 nm) apart latitudinally (Figure 2). In total, 75 stations were sampled on every trip (31 in CAI; 44 within and south of CAII).

For the purpose of the analysis, CAI stations were designated Western Georges Bank (WGB) and all stations within and outside of CAII were collectively designated Eastern Georges Bank (EGB). There was no significant difference in scallop catch (Mann-Whitney test, $U = 12{,}201$, $df = 352$, $p = 0.14$) within CAII and south of CAII in open area, however there was a significant difference in yellowtail (Mann-Whitney test, $U = 15{,}666$, $df = 352$, $p < 0.001$). Any differences in fish bycatch inside and outside CAII are more likely explained by depth, water temperature and fish migratory behavior than by differences in fishing pressure due to the management boundary.

Eight of the nine research trips used a vessel outfitted with one 4.57 m (15 ft) wide Coonamessett Farm Turtle Deflector Dredge (CFTDD) and one 4.57 m (15 ft) wide standardized New Bedford style dredge (NB dredge). The NB dredge had a 13 by 40 ring apron, a 9 by 40 ring bag, 6 by 17 ring sides, and a three-ring skirt (Table 1). The CFTDD had an 8 by 40 ring apron, a 10 by 40 ring bag, 6 by 18 ring sides and a two-ring skirt (Table 1). Both dredges 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 tops for both dredges had a stretched mesh length of 10.5 inches, and the hanging ratio for the NB dredge was 3 meshes to one ring, while the CFTDD was 2:1. The dredges were 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.

The dredges were towed at 4.8 knots using 3:1 wire scope. Tows were 30 minutes in duration, with a minimum tow time of 20 minutes in the case of technical difficulties. If the tow was less than 20 minutes in duration, the station was retowed. Captains were instructed to pass through the station coordinates at some point during the tow. All tow parameters were recorded, including start and end positions, depth, and sea conditions. Two water temperature loggers (one Vemco Minilog and one Star-Oddi milli-TD) were deployed in steel sheaths welded to the CFTDD to measure depth and temperature at each station.

In September 2012, two vessels surveyed concurrently: FV Liberty and FV Celtic. The FV Liberty used the standard sampling dredges (CFTDD and NB dredge), while the FV Celtic was outfitted with a standardized NB dredge and a 2.44 m (8 ft) NMFS survey dredge with a 3/8 inch liner and 2 inch rings. The purpose of this trip was to calibrate the NB dredge against the NMFS survey dredge. Because of the size of the NMFS dredge, the tow parameters had to be adjusted for this trip. Tow speed was reduced to 4.0 knots and tow duration was 15 minutes.

For each paired tow, the catch from each dredge was separated by species and individually counted. The entire scallop catch was quantified as bushels (bu = 35.2 liters). A one-bushel subsample of scallops was picked at random from each dredge on each tow. These subsamples were measured in 5 mm shell height increments and length frequency was recorded for each bushel. Size frequency could then be derived for the entire catch by multiplying the number of scallops of each size class in the subsample by the total number of bushels. The commercially important finfish species and barndoor skates were measured to the nearest centimeter. Winter and little skates were counted together, but not measured, and categorized as "unclassified skates." Table 2 lists all species that were measured and/or counted by common and scientific name. Composition and estimated quantity of "trash" (including rocks, sand dollars, crabs, sea stars, clams and shell debris) was also noted.

<u>Catch and Distribution</u>

Catch was quantified by area to identify seasonal and/or long-term patterns in scallop, flatfish (yellowtail, winter, windowpane, and summer), monkfish, and skate (barndoor and unclassified) catches. The total number of animals was calculated by area for the stations that were consistently sampled on the eight trips on which the NB dredge and the CFTDD were used: 31 stations on WGB (Figure 1) and 44 on EGB (inside and southwest of CAII) (Figure 2). Total fish caught per tow was analyzed since tow duration and speed were standardized, however, there may have been slight variation in area swept. Catch in both dredges combined was plotted for 2012 since both dredges were standardized (Figures 3-10). Catch in the CFTDD was also plotted for the duration of this project (May 2011-July 2013) for stations that were consistently sampled on all trips (Appendix A). It was not possible to calculate confidence intervals for this dataset, since we used a fixed sampling design.

Distribution of bycatch species was also mapped for all trips (May 2012-March 2013) to examine seasonal distribution patterns in these areas (Appendix B). The water temperature and depth measurements provided seasonal environmental data that may help to understand the factors driving patterns in fish distribution.

<u>Bycatch Rates</u>

Length-weight conversions (Wigley et al., 2003) were used to estimate the total weight of each fish caught during each survey tow. Fish weight was calculated by 3 cm length increments and scallop meat weight was calculated by 5 mm shell height increments. Bycatch rate was calculated for each trip by dividing the weight of fish bycatch (lbs) by meat weight of the scallop catch (lbs). Rates were plotted by area and dredge type, so as to allow general gear comparison. A low ratio is ideal for the fishery since it represents low fish bycatch in relation to scallop meat yield.

<u>Scallop shell height/meat weight relationship</u>

A subset of roughly 30 stations (15 per area) within the study areas were randomly selected for shell height to meat weight sampling. At each of these stations, 12 scallops representing a range of observed shell sizes were sampled. The top shell of each animal was measured to the nearest millimeter and the scallop was then carefully shucked. The meat was blotted dry, placed in a ZipLoc bag and individually frozen. Station number, shell height, sex, and reproductive stage were recorded for each meat sample. Upon return to port, the samples were separately weighed to the nearest 0.1 gram. Depth, location, and date of collection were also recorded for each sample.

Sea scallop meat weight was predicted using a generalized linear mixed model (gamma distribution, log link). Scallop shell height, depth, sampling area (either WGB or EGB), and month were used as explanatory variables. The mixed modeling approach used a true likelihood based estimation that has multiple advantages. Traditionally, data of this type have been analyzed by least squares regression of the linearized data (i.e. lnMW*lnSH; NEFSC, 2010). Some advantages of the mixed modeling approach are the ability to define the underlying distribution of the data. The distribution that was used in this analysis was the gamma distribution and is generally considered a more appropriate distribution for data of this type. This modeling approach also avoids the bias involved with back-transformations from log-linear models. In addition, random variation in the data can occur as a result of temporal and fine scale spatial variability in the process. Incorporating a random effect in the model accounts for this variability by evaluating the data at the station level and allows the intercept to be estimated for every time and station grouping. The station grouping variable consists of a unique code that included the year, month (temporal component), and station number (spatial component) from which the sample originated. This approach tends to capture and account for this variability more effectively relative to a model with only fixed effects. Information criteria such as AIC and BIC was used to select the best model configuration. Statistical analyses were completed using PROC GLIMMIX on the SAS v. 9.2. system.

Seasonal Effects on Sea Scallop Reproduction and Energetics

Samples were collected on each cruise to examine seasonal effects on sea scallop reproduction and energetics on Georges Bank. Live scallops (n = 30-50) in good condition and approximately 130 mm in shell height (SH) were collected from CAI-Station 26 (CAI-26) and CAII-Station 22 **(**CAII-22), which were selected based on proximity to persistent scallop aggregations. In the case that there were not enough scallops at the primary collection stations, nearby backup stations CAI-33 and CAII-23 were used. Samples were collected on every cruise from May 2012 to March 2013 survey cruises and immediately frozen whole on board. A subset (n = 10) of these samples was removed for proximate analysis.

The remaining samples were thawed, shell height measured using digital calipers, and the gonad was separated from the somatic tissue using a scalpel. The crystalline style, intestinal contents, and foot were removed from the gonads prior to drying and included with viscera weight. Gonads were oven-dried to constant weight at 80°C and the dry gonad weight was recorded. Gonosomatic index (GSI) was calculated (GSI = [Gonad Weight/Total Tissue Weight]*100, Barber and Blake, 2006). A Mann-Whitney test was used to identify statistical differences in mean GSI between months, since data were not normally distributed. Spawning events were identified by a significant difference in GSI between months where GSI decreased.

Samples collected for energetics were processed frozen to prevent enzymatic degradation of the tissue constituents. Shell height and reproductive condition were recorded and semi-frozen tissues were separated into adductor muscle, gonad, mantle, gills, and digestive gland.

Gonad tissue samples (n = 20: 10 females, 10 males) were collected at each station and preserved in formalin for histological analysis from May 2012 to March 2013. Reproductive stage was determined following the criteria of Naidu (1970). Oocyte diameter was measured using ImagePro. Data were not normally distributed, therefore a Mann-Whitney test was used to identify statistical differences in mean oocyte diameter between months. A significant difference in oocyte diameter between months where GSI decreased verified spawning.

Water temperature measurements at the sample collection stations were plotted to compare differences in seasonal patterns between these sites, since bottom temperature is know to be an important spawning cue and may influence gametogenesis (Schmitzer et al., 1991). Measurements were compared with Finite-Volume Coastal Ocean Model (FVCOM) data from 2000-2009 to provide annual daily profiles of the bottom temperature at these two stations (Chen et al., 2006).

The top shell from the samples for energetic analysis and a subset of top shells from the meat weight component of the bycatch survey were processed for isotope analysis. These shells were scrubbed clean of any exterior organic debris, rinsed with distilled water and then air dried. Shell carbonate powder was collected using a Dremel® diamond head drill with a flexible arm attachment. The outer shell layer was micro drilled every 0.5-1.0 mm along and parallel to the axis of maximum growth from umbo to shell margin. A minimum of 100 micrograms were collected from each sample site on the shell. The carbonate powder was transferred to a micro centrifuge tube and the samples have been submitted to a laboratory for ^{18}O isotope analysis. The samples were analyzed using Finnigan MAT 251 triple-collector gas source mass spectrometer coupled to a Finnigan Kiel automated preparation device. The isotope values were reported in the conventional delta δ notation as the enrichment or depletion of ^{18}O (parts per thousand ‰) relative to the Peedee belemnite (PDB) carbonate standard (Peterson and Fry, 1987). The predicted water temperatures during shell formation were determined using the paleotemperature equation by Epstein et al. (1953) and modified by Craig (1965):

$$\delta^{18}O_{(calcite)} = \delta^{18}O_{(water)} + \frac{4.2 - \sqrt{17.64 - 0.52(16.9 - T)}}{0.26}$$

$$\delta^{18}O_{(calcite)} = \delta^{18}O_{(water)} + \frac{4.2}{}$$

where T= ambient temperature (°C).

This value was correlated with temperature estimates from the FVCOM model (Chen et al. 2006) providing an estimated date of shell formation for each calcite sample site.

Yellowtail and Winter Flounder Maturity

Maturity data was collected for yellowtail and winter flounder on all valid tows on each research trip from May 2012 through March 2013. All fish (if less than 10 fish) or a sub-sample of 10 fish per species were sampled using the NEFSC 6-stage maturity criteria (Burnett et al., 1989).

Yellowtail Flounder Disease Study

At sea evaluation of yellowtail flounder was done for each scheduled bycatch trip. Fish were randomly collected throughout the sampling stations and necropsied until 60 tissue samples with abnormalities were collected. Each fish was dissected and visually examined to identify abnormalities focusing on the characteristic white lesions signifying *Ichthyophonus spp.* If nodules of any type were found, tissue samples were collected and fixed in 10% neutral buffered formalin for histological evaluation. After macroscopic examination, the fish were divided into three groups: no observable abnormalities, low numbers of abnormalities, and high numbers of abnormalities. Fish with no abnormalities observed were assumed to be healthy and these samples were not processed for histology. Fish were classified as having low numbers of abnormalities if the tissues appeared normal but nodules were present. Fish in the high abnormality group were identified by the high abundance of nodules and often the whitish sheen to the serosal surface of the peritoneal organs and/or abnormalities of the heart.

In the laboratory, the tissue samples were trimmed into histology cassettes and preserved in 70% ethanol. Tissues were embedded in paraffin and 6µm-sections were cut and stained with hematoxylin and eosin stains at an outside laboratory (Mass Histology Services, Inc., Worcester, MA). Parasites were identified microscopically and tissue damage was evaluated.

Area Swept Biomass Estimation

Catch Weight

The total length of each yellowtail flounder was measured to the nearest centimeter. The weight of each yellowtail flounder was calculated using the length-weight relationship established for yellowtail flounder by season (Wigley et al., 2003). Since no length-weight relationship is available for the summer season, weight-at-age was calculated as the average of the autumn and spring length-weight relationship values. All individual yellowtail flounder weights were summed for each tow for a total catch weight per tow.

Area Swept Estimates

Estimates of yellowtail flounder density (kg/km^2) and biomass (mt) were calculated by examining the observed catch of yellowtail flounder and the area swept by the standard survey dredge during each valid tow. The width of the survey dredge was 4.57 m (15ft.). The area swept by the survey dredge during each tow was calculated using the width of the dredge, the speed of the vessel during the tow, and the tow duration. Tow speed was converted from knots to km/hr for area swept estimation. Tow duration started when the dredge was on bottom with the winches locked, and ended when the winches were engaged to pull the dredge from the bottom. The duration of each tow was converted from minutes to fraction of an hour for area swept calculations.

Area swept (km^2) = dredge W (km) * tow speed (km/hr) * tow duration (hr) (2)

The catchability of the NEFSC survey dredge was estimated to be 0.46 for yellowtail flounder. The estimate of dredge catchability calculations was based on the ratio of yellowtail flounder caught in the NEFSC survey dredge to HabCam video observations of yellowtail flounder abundance in the southern portion of CAII (*per. comm*., Burton Shank and Dvora Hart). A comparative fishing experiment was completed in September 2012, and simultaneous survey tows were made using the NEFSC survey dredge on one side and the NB dredge on the other side. Yellowtail flounder catches were compared between the two dredges, and were plotted with a regression through the origin (Figure 11). The slope of the regression was 2.2848. This value was used to derive a catchability estimate for the NB dredge. The catchability for the NB dredge was calculated with the following equation.

NB dredge q = NEFSC survey dredge q / 2.2848 (3)

The density of yellowtail flounder observed in each survey tow was calculated as follows.

Yellowtail flounder density (kg/km^2) = yellowtail flounder catch(kg)/area swept (km^2) * (1/q) (4)

where, q is the NB dredge catchability coefficient.

The stations on WGB were 5.40 km by 7.17 km, and each station had an area of 38.74km^2. EGB stations were 8.54 km by 11.11 km, and each station had an area of 94.82km^2. Between 30 and 33 stations were sampled per trip on WGB (mean = 31.25), and between 43 and 45 stations were sampled each trip on EGB (mean = 44 stations) (Table 3). Therefore, the total area sampled varied between survey cruises, and ranged from 5334.5 km^2 in January 2013 to 5468.1 km^2 in June 2012 (Table 3). Estimates of yellowtail flounder density, which were calculated for each valid survey tow, were used to estimate the biomass of yellowtail flounder present in each area using the following formula:

Yellowtail flounder biomass (kg) = yellowtail flounder density (kg/km^2) * total station area (km^2) (5)

The biomass estimate derived from each survey trip was later converted from kilograms to metric tons to allow for comparison with biomass estimates derived from the Georges Bank yellowtail flounder stock assessment.

Gear Comparisons

The objective of these experiments was to determine if the two scallop dredges performed differently and how those differences might affect catch rates and size selection of both scallops and the major finfish bycatch species. We used a Generalized Linear Mixed Model (GLMM) to analyze the paired catch data and test for differences in both the pooled length catch data as well as test for differences in the length composition of the catch. Within this modeling framework, the random effects acknowledge the potential for differences that may have occurred at both the trip and individual tow levels. The GLMM groups all the data and gives an overall perspective on how the two gears compare.

The paired tow experiments were conducted within the context of the bycatch survey and covered a wide range of fishery conditions. This approach has the advantage of mirroring the actual biotic and abiotic conditions under which the dredge will operate. Multiple vessels and slight variations in gear handling and design were included in the experimental design and, while this variability exists, the GLMM modeling approach detailed in the next section accounts for the variability and allows for a broader inference (relative to vessels) to be made.

Statistical Models – GLMM

Catch data from the paired tows provided the information to estimate differences in the relative efficiency for the gear combinations tested. This analysis is based on the analytical approach in Cadigan et al. (2006).

Assume that each vessel/gear combination tested in this experiment has a unique catchability. Let q_r equal the catchability of the CFTDD and q_f equal the catchability of the NB dredge used in the study. The efficiency of the CFTDD relative to the NB dredge will be equivalent to the ratio of the two catchabilities:

$$\rho_l = \frac{q_r}{q_f} \qquad (6)$$

The catchabilities of each gear are not measured directly. However, within the context of the paired design, assuming that spatial heterogeneity in scallop/fish and fish density is minimized, observed differences in scallop/fish catch for each vessel will reflect differences in the catchabilities of the gear combinations tested.

Let C_{iv} represent the scallop/fish catch at station i by dredge v, where $v=r$ denotes the CFTDD and $v=f$ denotes the NB dredge. Let λ_{ir} represent the scallop/fish density for the i^{th} station by the CFTDD and λ_{if} the scallop/fish density encountered by the NB dredge. We assume that due to random, small scale variability in animal density as well as the vagaries of gear performance at tow i, the densities encountered by the two gears may vary as a result of small-scale spatial heterogeneity as reflected by the relationship between scallop/fish patch size and coverage by a paired tow. The probability that a scallop/fish is captured during a standardized tow is given as q_r and q_f. These probabilities can be different for each vessel, but are expected to be constant across stations. Assuming that capture is a Poisson process with mean equal to variance, then the expected catch by the CFTDD is given by:

$$E(C_{if}) = q_f \lambda_{if} = \mu_i \tag{7}$$

The catch by the NB dredge is also a Poisson random variable with:

$$E(C_{ir}) = q_r \lambda_{ir} = \rho \mu_i \exp(\delta_i) \tag{8}$$

where $\delta_i = \log(\lambda_{ir}/\lambda_{if})$. For each station, if the standardized density of scallops /fish encountered by both dredges is the same, then $\delta_i=0$.

If the dredges encounter the same scallop/fish density for a given tow, (i.e. $\lambda_{ir}=\lambda_{if}$), then ρ can be estimated via a Poisson generalized linear model (GLM). This approach, however, can be complicated especially if there are large numbers of stations and scallop/fish lengths (Cadigan et al., 2006). The preferred approach is to use the conditional distribution of the catch by the CFTDD at station i, given the total non-zero catch of both vessels at that station. Let c_i represent the observed value of the total catch. The conditional distribution of C_{ir} given $C_i=c_i$ is binomial with:

$$\Pr(C_{ie} = x \mid C_i = c_i) = \binom{c_i}{x} p^x (1-p)^{c_i - x} \tag{9}$$

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish captured by the CFTDD dredge. In this approach, the only unknown parameter is ρ and the requirement to estimate μ for each station is eliminated as would be required in the direct GLM approach (equations 7 & 8). For the binomial distribution $E(C_{ir})=c_i p$ and $Var(C_{ir})=c_i p/(1-p)$. Therefore:

$$\log\left(\frac{p}{1-p}\right) = \log(\rho) = \beta \tag{10}$$

The model in equation 10, however, does not account for spatial heterogeneity in the densities encountered by the two gears for a given tow. If such heterogeneity does exist then the model becomes:

$$\log\left(\frac{p}{1-p}\right) = \beta + \delta_i \tag{11}$$

where δ_i is a random effect assumed to be normally distributed with a mean=0 and variance=σ^2. This model is the formulation used to estimate the gear effect $exp(\beta_0)$ when catch per tow is pooled over lengths.

Often, gear modifications can result in changes to the length based relative efficiency of the two gears. In those instances, the potential exists for the catchability at length (l) to vary. Models to describe length effects are extensions of the models in the previous section to describe the total scallop catch per tow. Again, assuming that between-pair differences in standardized animal density exist, a binomial logistic regression GLMM for a range of length groups would be:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_i + \beta_1 l, \delta_i \sim N(0, \sigma^2), i = 1, \ldots, n. \tag{12}$$

In this model, the intercept (β_0) is allowed to vary randomly with respect to station.

The potential exists, however, that there will be variability in both the number as well as the length distributions of scallops/fish encountered within a tow pair. In this situation, a random effects model that again allows the intercept to vary randomly between tows is appropriate (Cadigan and Dowden, 2009). This model is given below:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_{i0} + \beta_1 * l, \delta_{ij} \sim N(0, \sigma_j^2), i = 1, \ldots, n, j = 0,1. \tag{13}$$

Adjustments for sub-sampling of the catch

Additional adjustments to the models were required to account for sub-sampling of the catch. In most instances, due to high scallop catch volume, particular tows were sub-sampled. This is accomplished by randomly selecting a one bushel sample for length frequency analysis. Finfish were always sampled without subsampling. One approach to accounting for this practice is to use the expanded catches. For example, if half of the total catch was measured for length frequency, multiplying the observed catch by two would result in an estimate of the total catch at length for the tow. This approach would overinflate the sample size resulting in an underestimate of the variance, increasing the chances of spurious statistical inference (Millar et al. 2004; Holst and Revill 2009). In our experiment, the proportion sub-sampled was not consistent between tows as only a one bushel sub-sample was taken regardless of catch size. This difference must be accounted for in the analysis to ensure that common units of effort are compared.

Let q_{ir} equal the sub-sampling fraction at station i for the vessel r. This adjustment results in a modification to the logistic regression model:

$$\log\left(\frac{p_l}{1+p_l}\right) = \beta_0 + \delta_i + (\beta_1 * l_l) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1, \ldots, n. \tag{14}$$

The last term in the model represents an offset in the logistic regression (Littell et al. 2006).

Our analysis of the efficiency of the CFTDD relative to the NB dredge consisted of multiple levels of examination. For all species, the full model consisted of unpooled (by length) catch data:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0,\sigma_j^2), i = 1..n, j = 0,1\ldots \tag{15}$$

The symbol f_{ij} equals the categorical variable denoting dredge frame configuration. Model fit was assessed by AIC. If AIC and factor significance indicated that length was not a significant factor in predicting relative efficiency, the data was pooled over length. The random intercept model, was evaluated to asses relative differences in total catch (see equation 11).

We used SAS/STAT® PROC GLIMMIX v. 9.2 to fit the generalized linear mixed effects models.

RESULTS

Catch and Distribution

Scallop catch was greatest in May 2012 on EGB and in June 2012 on WGB with catch decreasing over the time series in both areas due to high fishing effort (Tables 4 and 5, Figure 3).

Yellowtail flounder catch was low and distribution was fairly uniform on WGB (Figure 4, Appendix B Figures 1 and 2). Yellowtail catch was consistently higher on EGB than on WGB and peaked at 1,351 fish in September 2012 (Tables 4 and 5, Figure 4). Catch was greatest in northeastern CAII in September 2012 (Appendix B Figure 3) when bottom temperatures ranged between 12-13° C (Table 7). This fall peak in yellowtail catch is consistent with 2011 (Appendix A Figure 4). Moderate yellowtail catches were then observed in open area south of CAII in December 2012 in 10.5° C bottom water (Table 7, Appendix B Figure 4).

Winter flounder catches were high on WGB, peaking at 230 fish in August and November 2012, whereas levels remained low on EGB (Tables 4 and 5, Figure 5). These summer and winter peaks on WGB are consistent with 2011 patterns in catch (Appendix A Figure 5). In May and June 2012 fish were caught in southern CAI (Appendix B Figure 5), whereas catch was higher in northern CAI in August and September 2012 (Appendix B Figure 5). In November, catch was high in northern CAI and in December winter flounder were observed in southern portion of CAI (Appendix B Figure 6).

Windowpane flounder hovered under 650 fish in both areas, until January 2013, when 2,765 fish were observed on EGB (Tables 4 and 5, Figure 6). Windowpane seemed more common in southeastern CAI in shallow water (~60 m) year round (Appendix B Figure 9 and 10). On EGB, windowpane catch was low from May through September 2012 on EGB (Appendix B Figure 11), increased in November and December 2012, and was extremely high in March and January 2013 (Appendix B Figure 12).

Summer flounder catch was minimal, never exceeding 70 individuals (Figure 7). Summer flounder catch was greatest on WGB during the summer months, but was otherwise relatively low (Appendix B Figures 13-16).

Monkfish catch was greatest in June 2012 at 430 fish on WGB and in August 2012 on EGB at 692 (Tables 4 and 5, Figure 8). Monkfish were common on the northern border of CAI in June and August 2012, were widely distributed from May through September 2012 on EGB and then were caught mostly in open bottom south of CAII in November and December 2012 (Appendix B Figures 17-20).

Barndoor skate catch reached maxima in August 2012 on WGB (150 skates) and in September 2012 on EGB (378 skates; Tables 4 and 5, Figure 9). Barndoor skates were widely distributed on WGB in August 2012 and then moved up to the northern border of CAI in September (Appendix B Figure 21). Barndoors were seen mostly south of CAII from August through December 2012 (Appendix B Figure 23). Unclassified skates were by far the most plentiful bycatch species with ~43,000 individuals caught per area (Tables 4 and 5, Figure 10).

Bycatch Rates

Bycatch rates followed similar trends as fish catches, but represent the weight of bycatch species in relation to scallop weight (lbs fish/lbs scallops). Yellowtail bycatch rates peaked at 0.45 in November 2012 on EGB (Table 8, Figure 12). The bycatch rate of winter flounder was highest in November 2012 on WGB with a modal pattern unlike the bimodal trend in catch (Table 9, Figure 13). Windowpane bycatch rates were consistent with catches, with a peak at 0.71 in January 2013 on EGB (Table 10, Figure 14). Summer flounder bycatch was low, but bycatch rate was highest in September 2012 on WGB (Table 11, Figure 15). Monkfish bycatch rate was quite variable, reaching maxima in November 2012 on WGB (0.94; Table 12) and in August 2012 on EGB (0.88; Table 12, Figure 16). Barndoor skate bycatch rate was extremely high (0.95) for the NB dredge on WGB in November 2012 (Table 13, Figure 17). The NB dredge caught considerably more barndoor skates by weight than the CFTDD on WGB for all trips. Unclassified skates were not measured, so bycatch rate could not be calculated for these species.

Scallop shell height/meat weight relationship

Over nine cruises from May 2012 through March 2013, a total of 2,860 scallops were sampled at 236 unique stations. Scallop shell heights ranged from 76 mm to 175 mm and meat weights varied from 6 g to 82 g. Log transformed shell height and meat weight data with various groupings (area, month) are shown in Figures 18-20.

Candidate models were evaluated and the model that produced the lowest AIC value was chosen as the model that best fit the data. Combinations of explanatory variables that were evaluated and resulting AIC values are shown in Table 14. The selected model is shown below:

$$MW = e^{(\beta_0+\delta+\beta_1*\ln(SH)+\beta_2*(M)+\beta_3*(A)+(\beta_4*(M)*(A))+\epsilon)} \tag{16}$$

Where δ is the random effect term (intercept), MW is scallop meat weight in grams, SH is shell height in millimeters, M is month when the sample was taken, A is area (WGB or EGB) and an interaction term between month and area.

Based on an examination of residuals and QQ plot (Figure 21) model fit appears to be reasonable. There do appear to be a few outliers that consist of both heavier and lighter than expected meats. These observations could represent natural anomalies such as a diseased or senescent animal or simply an extraordinarily robust animal. While every effort was made to verify the quality of the data, some measurement error could exist in the data set. Regardless, the outliers were few and had minimal impact on parameter estimates.

Parameter estimates (Table 15) were reasonably precise and predicted increasing meat weight as a function of increased shell height. Meat weights were consistently higher on WGB relative to EGB and the temporal trend indicated that meat weights were elevated from May - August 2012 and decreased from September - December 2012. Temporal trends of a modeled 120 mm scallop for the two areas are shown in Figure 22. Estimated curves by month for the two areas are shown in Figures 23-24.

Seasonal Effects on Sea Scallop Reproduction and Energetics

Spawning was semiannual in both areas in 2011 and 2012 (Figure 25). GSI was significantly different between months (Mann-Whitney test, $p < 0.05$) where values were decreasing in both the spring (May to June) and the fall (September to October) of both years, indicating that spawning was semiannual (Figure 25). The magnitude of the fall spawning event was greater than spring spawning at the two stations in both years (Figure 25).

Results from histological analysis indicated that mean oocyte diameter closely followed patterns in mean GSI and confirmed semiannual spawning in both years (Figure 26). Preserved sample collection began in June 2011, which was after the spring spawning event. However, June samples provided qualitative histological evidence that confirmed spring spawning in 2011; vacancies in the center of follicles indicated gamete release (Figure 27).

Preliminary results on seasonal changes in the composition of adductor muscle in scallops of ~130 mm SH, 100-110 mm SH (small), and >145 mm SH (large) from CAI and CAII are presented in Figures 28, 29 and 30. Results were statistically analyzed by initially performing a Shapiro-Wilk test for normality. As the data were found to be normal, the data were analyzed using ANOVA and Tukey's tests where there were significant differences. All statistical tests were performed using SPSS statistical software. Significance level was set to the alpha level of 0.05. All values are based on wet weight.

There was no significant difference in the ash or fat content between month and area (ANOVA: $p > 0.05$) in all size classes tested (Figures 28-30). There was a significant difference in moisture, protein and carbohydrate (crude glycogen) content between month and area for scallops 130 mm SH (ANOVA: $p < 0.05$; Figure 30). Carbohydrate values in the 130 mm size class peaked in May in CAII and in June in CAI followed by a decline in both areas (Figure 30). Tissue samples in the 100-110 mm SH size class had to be pooled to provide enough tissue for analyses and thus no measure of variance is provided. In the small class size (100 - 110mm SH) the carbohydrate value peaked in May and then declined in both areas (Figure 28). The carbohydrate results for the large size classes (> 145 mm SH) had a very high variance but there appeared to be a trend in this size class as well, with a peak occurring in May –June and then a decline (Figure 29). However, sample collection of the small and large size classes did not begin until May 2012 and thus the results do not yet represent a full year. We are continuing to collect samples in all size classes in 2013 to increase our sample size so that we can compare results between size classes and improve statistical power in the current analyses. The % fat content in all scallop meat tested was l% or lower but consistent with other studies (Naidu and Botta, 1978; Krzeczkowski et al., 1972; Robinson et al., 1981; Webb et al., 1969). Nevertheless, to confirm the low fat content in our results, a subsample of the meats will be analyzed using the Bligh Dyer lipid extraction method (AOAC, 2011) as well as the ether extraction method (used in this analysis). The results from the two methods will be compared.

Moisture, protein and moisture:protein ratios are presented in Table 16. These values are important indicators of meat condition representing "water-added" when marketing scallop meats and are carefully monitored by the FDA and US Department of Agriculture (USDA). All scallops in the large size class, independent of area, had naturally occurring maximum %

moisture values above the 80% limit used by FDA and USDA. Our results suggest that the moisture:protein ratio provides a more consistent value for moisture levels in unprocessed scallop meat. However, large scallops in southern CAI had very high moisture:protein values well above the 5.0 ratio limit used by regulators.

Results from the temperature loggers suggest that bottom temperature patterns are different between CAI-26 and CAII-22 from year day 170 to 301 (June 19 to October 28; Figure 31). Bottom temperatures fluctuate more widely on a seasonal basis at CAI-26 (7.0 - 17.6° C) than at CAII-22 (6.2 – 11.9° C).

Preliminary results from stable isotope analysis of shell carbonate from scallop samples collected from CAI-26 and CAII-22 also show a significant difference in oceanographic conditions between the two stations (Figure 32). The ^{18}O signature (in red) represents ambient water temperature when the shell was laid down and thus an archive of water temperatures experienced by the scallop (Figure 32). Peaks in the graph indicate cool water temperatures (winter-spring) and troughs represent warmer water temperatures (summer-fall) (Figure 32). Analysis of this data set will continue into 2013. We are currently back calculating water temperature from the ^{18}O signature.

Yellowtail and Winter Flounder Maturity

Yellowtail Flounder

In total, 2,279 yellowtail flounder were measured and staged for maturity with 1,734 females, 543 males and 2 unknown due to infection. The mean size of all females sampled was 38.63 cm and 34.00 cm for male yellowtail flounder (Table 17). The maturity of yellowtail indicated a spawning event in the spring peaking around May 2012, followed by yellowtail flounder resting until September/ November when they began to develop for the next spawning season (Figures 33-40).

Winter Flounder

The winter flounder sample size was 846 fish measured and staged for maturity between 583 females and 263 males. The mean size of all females sampled was 42.13 cm and 38.35 cm for male winter flounder (Table 17). Winter flounder were ripe in January and transitioned to ripe and running by March, with most fish visibly spent or resting beginning in June and then starting to develop in November (Tables 18-21).

Yellowtail Flounder Disease Study

During the 2012 bycatch surveys, 562 yellowtail flounder were examined for disease, and 25.1% of these fish had no visible *Ichthyophonus* or other significant parasites. Low levels of abnormalities were seen in 72.4% of the fish dissected, and 2.5% of the fish had high abnormality levels (Figure 41); samples from each of these groups were processed for histology. Histological evaluation has been completed for May through December 2012 samples, whereas samples from January and March 2013 are still being processed. Microscopic examination of samples with low infection levels has shown that the majority of the nodules were not caused by *Ichthyophonus* sp. infection, but were due to a variety of other parasites, including nematodes and cestodes (Figure 42). Early stages of *Ichthyophonus* were found in 2% of the samples with low numbers of abnormalities, and presented most commonly as foci of infection in the liver or as microscopic lesions. *Ichthyophonus* is more prevalent in large fish (> 37 cm), than in small fish (< 37 cm) (Table 22). Samples with high levels of abnormalities were all positive for *Ichthyophonus* sp. In almost all cases, other parasites were present. *Ichthyophonus* appeared to target organs with high blood flow such as the heart, liver, and gonads and often resulted in tissue necrosis and inflammation. All highly infected animals have shown severe myocardial infection (Figures 43), with myocardial necrosis and myocarditis and both endo- and epicarditis (Figure 44).

Area Swept Biomass

The mean density (kg/km^2) and biomass (mt) of yellowtail flounder on WGB and EGB were calculated for each survey trip. A preliminary estimate of the catchability of the NEFSC survey dredge was used to derive an estimated catchability of the NB dredge. The catchability of the NB dredge was estimated to be 0.201 for yellowtail flounder. Estimates of yellowtail flounder biomass and density are sensitive to the catchability of the NB dredge. To quantify the sensitivity of the yellowtail flounder biomass estimate to the assumed catchability value (q), a series of calculations were performed, using assumed catchability values that ranged from 1.0 to 0.1 (Table 23).

Scallop catch and bycatch were considerably lower in the NB dredge towed by the F/V Celtic at 4.0 kt as compared with catches in the NB dredge towed by the F/V Liberty at 4.8 kt in September 2012. Tow time was shorter (15 minute versus 30 minutes) aboard the F/V Celtic, however catches still remained disproportionately low (Table 24). Yellowtail catch on the F/V Celtic was only 15% that of the F/V Liberty, whereas catches of other species were about a third of the F/V Liberty's catch (Table 24).

Estimates of yellowtail flounder biomass and density varied markedly between sampling trips made from May 2012 and March 2013 (Figure 45). Results suggest that the biomass of yellowtail flounder on EGB is much greater than the biomass present on WGB (Table 25). Overall, the mean biomass estimate of yellowtail flounder for WGB was 174.94mt. The lowest biomass estimate was observed in September 2012 (36.9mt) and the largest estimate was observed in May 2012 (418.5mt). The mean biomass estimate of yellowtail flounder on EGB was 3950.72mt. The lowest estimate of biomass was observed on the June 2012 trip (1276.4mt) and the largest biomass was observed during the September 2012 trip (7291.9mt). The most recent Georges Bank yellowtail flounder stock assessment calculated a rho-adjusted age 1+ stock biomass of 1,131mt in 2012 (Table 25; TRAC, 2013 and Chris Legault, *pers. comm*). For each of the nine survey trips the area-swept estimates of yellowtail flounder biomass derived from the survey were greater than the estimates of age 1+ biomass produced by the stock assessment model.

Gear Comparisons

Catch data

Data from the eight research trips were treated as a single data set for the purpose of this analysis, since the configuration of the CFTDD (experimental) and the NB dredge (control) (Table 1) was consistent for all cruises.

Overall, 608 valid tow pairs were examined in the analysis. Not all species were present in all tow pairs and for the species examined, individual tows with zero total catch for a given species were uninformative and excluded from the analysis.

Statistical models

This analysis attempted to construct a model that would predict the relative efficiency of the CFTDD (experimental) relative to the NB dredge (control) tested in the experiment based on a variety of covariates. In many instances, especially with gear modifications that can possibly alter the relative size composition of the catch, using the unpooled catch data and exploring the length based relative efficiency can be informative. This analysis utilizing the unpooled catch data predicts the changes that the CFTDD had on the relative catch at length for the two experiments. For many species, however, length was not a significant predictor of relative efficiency. In these cases, an overall change in the relative total catch was possible and tested via a model specification using the pooled catch data.

Model Results

For some species (American plaice, grey sole, four spot flounder, dogfish), there was simply not enough data to provide meaningful results from the model. Most cases involved a small number of tow pairs where there were non-zero observations and the model failed to converge. These species were excluded from the analysis due to small sample size. Table 26 shows the best model fit as determined by AIC for the various species in the analysis. Parameter estimates associated with the best model fit are shown in Table 27. Graphical representations of the observed catches (either pooled or unpooled depending upon best model fit) and predicted relative efficiencies derived from the model output are shown in Figures 46-52.

Sea scallops and barndoor skate were the only species where the length-based model provided the best fit to the data. Figures 53-56 present the graphical results for these species as a function of length. Across species, there was an overall reduction in relative efficiency using the CFTDD configuration relative to the NB dredge as length increased. For barndoor skates and scallops, the reduction in relative efficiency with respect to size was slight. This suggests a characteristic of the gear that either facilitates the escape of smaller animals after capture or a mechanism to deter smaller animals from entering the gear.

Animal length was not a significant predictor of relative efficiency for many of the species analyzed and the catch data was pooled over length. Parameter estimates were negative for the species (winter flounder, windowpane flounder, unclassified skates) where there was a significant difference in total catch between the CFTDD and NB dredge. This indicates that the CFTDD reduced the catch of the aforementioned species relative to the NB dredge. Of the species examined in this group, the relative total catches of yellowtail flounder and monkfish were not significantly different between the two gears. It is interesting to note that of the species that were significant in the model that included length, none of them were significant in the pooled analysis. This indicates that there were differences in the size composition of the catch, but not in the overall numbers caught. Parameter estimates for this model specification are shown in Table 28. Scatter plots with the observed catches as well as the estimated relative efficiencies are shown in Figure 46-52.

DISCUSSION

Catch and Distribution

The steady decline in scallop catch that was observed from May 2012 to March 2013 indicates intensive fishing in both areas, especially in CAI. This study provides more detailed data on the rate of fishing at fixed stations, which fishery dependent observer data does not offer. This could potentially inform fishing effort control measures in the future.

Bycatch patterns in 2012 were generally consistent with 2011 fish catches (Appendix A). Yellowtail flounder catch was highest on EGB in September over the course of this project, which is consistent with the fall peak in 2011 (Appendix A Figure 1). Flatfish and monkfish catch followed a very similar pattern to the 2011 survey, whereas there was more interannual variation in skate bycatch for both barndoor and unclassified skates.

The fish distribution data combined with the reproductive maturity data collected on this survey will help to identify the timing of yellowtail and winter flounder spawning and define Essential Fish Habitat. Yellowtail flounder were caught southwest of CAII in open area when they were ripe in May on EGB and then were spent when they moved northeast into CAII (Figure 33, Appendix B Figure 3). Winter flounder appeared to migrate northwest in May into June 2012 on WGB, and then move south-southeast from November into December 2012 (Appendix B Figures 5 and 6). We postulate that winter flounder moved into deep water north of the Channel in the summer then returned to shallower water south or southeast of CAI to spawn in the winter. This could have been a portion of the Georges Bank stock, which is believed to spawn offshore (Bigelow and Schroeder, 1953).

Understanding seasonal changes in catch and distribution of bycatch species on a finer scale will also inform the timing of rotational management closures and may be important in redefining closed area boundaries.

Bycatch rates

For most fish species bycatch rate was low in May and June 2012 as well as in March 2013. This is logical since there were few fish (Figures 5, 6, 7, 9 and 10), with the exception of summer flounder, and meat yield was highest (Figure 22) during these months. However, unclassified skates were abundant at those times. Therefore, efficiency of the scallop fishery may be optimized in the spring months, and especially in June.

SH:MW Relationships

Spatially and temporally explicit fishery independent length weight information tends to be difficult to obtain on the scale that was collected on this study. These results document trends between the two areas on a monthly basis, demonstrate the differences between the two areas and can be used in combination with the bycatch data included in this study to formulate a strategy to optimize the harvest of sea scallops in the Georges Bank Closed Areas.

Seasonal Effects on Sea Scallop Reproduction and Energetics

Dry weight and histological analysis confirmed that spawning was semiannual in both areas in 2011 and 2012. The spring peak in carbohydrate content observed in the proximate analysis of the scallop adductor may be a compositional modification associated with the semi-annual spawning as it coincides with changes in the GSI. We are awaiting results from energetic analysis conducted on gonad samples to confirm this energy transition. Our results confirm that glycogen is the major energy source for scallop adductor muscle tissue.

Different bottom temperature patterns at CAI-26 and CAII-22 represent differing physical oceanographic conditions and may explain the disparity in GSI between areas. Depth at CAI-26 and CAII-22 only differs by approximately 15 meters, but varying oceanographic dynamics could result in lower food availability at CAII-22 than at CAI-26. Lower food availability is a possible explanation for the observed differences in GSI between these locations. However, preliminary results from proximate analysis of scallop meat show higher carbohydrate values in CAII than CAI in small and 130 mm size classes. The ^{18}O isotopic signatures in the shells of scallops from CAI suggest that this population experiences a well-mixed environment and warmer water temperatures in the summer and fall. The ^{18}O isotopic signatures from scallops collected from CAII represent a stratified environment with this population experiencing consistently cooler water temperatures. Energetic analysis of scallops is continuing in 2013 and these new samples and further investigation into oceanographic conditions (currents, substrate etc.) in CAI-26 and CAII-22 is required to explain this paradox.

Results from this study also show that the moisture:protein ratio is a better standard to regulate “added water” in scallop products than % moisture content. Our outlier in the ratio category was in large scallops from the southern portion of CAI. This population experienced a significant increase in meat quality issues (gray meat) in 2012. A recent RSA study conducted by SMAST on what causes gray meat in sea scallops found that the condition is associated with increased myodengeration. Thus, the high moisture:protein ratio could represent the poor meat quality condition in this population.

Semiannual spawning has major implications for the stock assessment and management of the Georges Bank fishery. A biannual spawning pattern directly affects growth estimates and shell height/meat weight relationships, which would alter yield projections and fishery allocations. Further research needs to be conducted to understand the implications of semi annual spawning on annual meat weight relationships and recruitment.

Yellowtail and Winter Flounder Maturity

Yellowtail flounder

The results of the maturity staging for yellowtail flounder on Georges Bank indicate a peak spawning event in May, which coincides with maturity data collected in 2011. These results are relatively consistent with the spawning period indicated by Collette and Klein-MacPhee (2002), who indicate peak spawning on Georges Bank occurs during April/May.

Females first showed signs of development in September, and by December both sexes were 97 - 100% developed. Development appears to be earlier than maturity data collected in 2011 indicates, however the sample size was 52% less than the previous year's study.

Winter Flounder

The maturity staging results were consistent with last year's results indicating winter flounder spawn on Georges Bank between February and March, with most fish visibly spent or resting beginning in June, and then starting to develop in November. These results are similar to those reported by Collette and Klein-MacPhee (2002), which indicates spawning time differs as you travel north along the coast but still occurs between December and March. The sample size of winter flounder (n=1,846) is quite low and decreased by 37% compared to the 2011 study.

Although both species had a reduced sample size, the male to female ratio stayed the same, (yellowtail flounder 73% female, winter flounder 66% female) and the mean size of both females and males stayed the same.

Yellowtail Flounder Disease Study

The majority of yellowtail flounder sampled in this study hosted a variety of parasites including *Ichthyophonus* species as well as nematode and cestode parasitism. Many of the nodules found in fish with low infection levels were likely caused by nematodes and cestodes, which also may result in granulomatous inflammation and granuloma formation associated with gastritis and peritonitis. Moderate or severe parasitism could potentially result in dehabilitation of the fish and could increase the chance of predation.

Flounders infected with *Ichthyophonus* were found throughout the sample area, so it does not appear to be associated with a specific geographic location. It is possible that infection is seasonal, since 7 of the 19 confirmed cases of *Ichthyophonus* were collected in November 2012. All fish with high *Ichthyophonus* infection levels showed severe myocardial infections. These lesions would significantly weaken the heart, resulting in severe limitation of the movement of the fish and thus either predation or death from overexertion. No lesions were identified that indicated healing from damage caused by the infectious organism. Large fish eat more potentially infected prey and therefore may have a higher chance of exposure compared to small fish. Since *Ichthyophonus* is more prevalent in large fish that have higher reproductive potential, it may influence reproductive success.

Preliminary histological results suggest that *Ichthyophonus* may spread quickly through tissue causing significant damage and resulting in mortality or dehabilitation. However, further research is needed to determine how long the disease takes to spread from initial to lethal infection levels as well as to determine the extent of mortality due to *Ichthyophonus* infection.

Area Swept Biomass

The catch rates (and subsequent biomass estimates) of yellowtail flounder varied between survey trips both on WGB and EGB. On WGB, bycatch rates were greatest between May and August of 2012, and bycatch declined in September and November of 2012. Bycatch rates were moderate in December 2012, but declined again in January and March of 2013. On EGB, the highest bycatch rates were observed in September and November of 2012. Bycatch rates were lowest in May and June of 2012, and were intermediate during the winter in 2013. The variability in catch rates between trips suggests that the spatial distribution of yellowtail flounder varies during the course of the year. Reports from fishermen and the SMAST Yellowtail Flounder Bycatch Avoidance System suggest that large numbers of yellowtail flounder migrate into CAII in late summer and early fall (*per. comm*. Greg DeCelles).

The catchability estimate for the NB dredge that was estimated from the F/V Celtic trip results from September 2012 is merely an estimate. Catchability of the NB dredge may have been underestimated since it appears that catch was influenced by the slower tow speed. Tow speed will be accounted for in the catchability calculations in the 2014 RSA proposal.

Changes in the seasonal distribution of the yellowtail flounder resource can have important implications for survey results and stock assessments, and can also affect the bycatch rates of the scallop fishery on Georges Bank. Therefore, it is important to document changes in the seasonal distribution and catch of yellowtail flounder. This survey is unique in that yellowtail flounder were sampled throughout the year on WGB and EGB. It offers valuable data that can be used to inform the design of resource surveys as well as assist in the development of new management measures.

The estimate of age 1+ yellowtail flounder biomass derived from the bycatch survey was greater than the age 1+ biomass estimate from the most recent yellowtail flounder assessment for each of the nine survey trips that were conducted (TRAC, 2013). Biomass estimates from the bycatch survey are conservative, because the footprint of the bycatch survey only covers a relatively small portion of the entire Georges Bank stock area. These results provide strong evidence that the yellowtail flounder assessment may be severely underestimating the size of the population on Georges Bank. The split-series VPA model used in the assessment is plagued by a number of diagnostic problems, and a consistent retrospective trend is present in the model output.

Gear Comparisons

Our results indicate that in some cases, the modifications to the dredge frame resulted in differences in the catch of both the target species as well as the common bycatch species encountered during the survey. For a number of species the modeling efforts resulted in significant differences in the length composition of the catches between the two dredges, while in other cases only the total numbers of animals differed. The CFTDD caught fewer flatfish (winter and windowpane flounder) and skate bycatch compared with the NB dredge, while retaining comparable scallop catch.

These results provide insight into how dredge frame modifications affect individual species or similar groups of fish. With this insight, further modifications can be made in an attempt to facilitate additional reductions in bycatch. It is also important to verify the effect that dredge frame modifications have with respect to scallop catch as this is a significant factor in any gear modification.

Conclusion

This project has yielded valuable information on bycatch reduction via gear design, seasonal fish distribution, life history of scallops (reproduction, growth, and energetics) and flatfish (reproduction), pathological studies of scallops and yellowtail, and stock assessment parameters such discard mortality for flatfish. It has also served management of the scallop industry by effectively monitoring flatfish bycatch in Closed Areas I and II. Results from the bycatch survey informed the change of access area closures in Framework 24 from February 1-June 14 to CAII being closed from August 15-November 15 due to high yellowtail bycatch in the late summer and fall (NEFMC, 2013).

The bycatch survey provides a means of collecting data to address contemporary management issues such as distribution and prevalence of bycatch species of new concern (e. g. windowpane flounder), habitat characteristics and scallop meat discard rate. On the upcoming October 2013 bycatch trip scallop meat discards will be calculated from dredge damage, shucking and washing scallops in order to provide a more accurate estimate for the Scallop Planning Development Team. In the 2014 Bycatch RSA proposal we propose to monitor seasonal changes in benthic epifauna and habitat characteristics as well as continue biological sampling.

Presentations

Goetting, K., A. Barkely, S. Inglis, K. Thompson, D. Rudders, and R. Smolowitz. Contributing to management decisions through a comprehensive scallop survey on Georges Bank. 19th International Pectinid Workshop. Florianopolis, Brazil. April 10-16, 2013.

Smolowitz, R., C. Huntsberger, K. Goetting, R. Smolowitz. *Ichthyophonus* species effects on yellowtail flounder in special access areas on Georges Bank. MFI Workshop on Incorporating Environmental Change in Assessments and Management. Fairhaven, MA. May 7-8, 2013.

Thompson K., S. D. Inglis, K. D. E. Stokesbury. Identifying Spawning Events of the Sea Scallop, *Placopecten magellanicus*, on Georges Bank. 104th Annual Meeting of the National Shellfisheries Association. Seattle, WA. March 25-29, 2012. Received 2012 Gordon Gunter Award.

Thompson K., S. D. Inglis, K. D. E. Stokesbury. Identifying Spawning Events of the Sea Scallop, *Placopecten magellanicus*, on Georges Bank. Southern New England Chapter of the American Fisheries Society. Groton, CT. January 16, 2013.

Thompson K., S. D. Inglis, K. D. E. Stokesbury. Identifying Spawning Events of the Sea Scallop, *Placopecten magellanicus*, on Georges Bank. 19th International Pectinid Workshop. Florianopolis, Santa, Catarina, Brazil. April 10-16, 2013.

Thompson, K. Sex Down Under: The Secret Life of Sea Scallops. 3rd Annual Three Minute Thesis Competition at the University of Massachusetts Dartmouth. North Dartmouth, MA. May 10, 2013. Received 2nd place award.

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Table 1. Specifications for the CFTDD and NB dredge.

Head Bail Design	Turtle Dredge	New Bedford Dredge
Dredge ID	CFTDD	NB Dredge
Type of Chain for Turtle Mat	3/8" Grade 70	3/8" Grade 70
Up and Downs	13	13
Tickler Chain	9	9
Type of Chain for Sweep	Long Link Grade 80	Long Link Grade 80
Number of Links in Sweep	121 long links	121 long links
Chain Sweep Hanging	12 link dog chain for the first ring 6 links in; 9 link dog chains every 4 links and 2 rings with 11 link dog chains in the corners; every 4 rings in the bag (6,4,4,2,4…)	12 link dog chain for the first ring 8 links in; 9 link dog chain every 4 links and 2 links with 11 link dog chain in the corners; 4 in the bag (8,4,2,4…)
Twine Top	2:1 with two in the sides	3:1 with two in the sides
Diamonds	14	14
Skirt	2X28 or 2X40 with dog chain	3X28 or 3X40 with shackles
Sides	6X18 or 6X20	6X17 or 6 X20
Apron	8 X 40	13 X 40
Bag	10 X 40	9 X 40
Chaffing Gear	Sewn in three rows down from the sweep for the bag and on the diamonds	Sewn in three rows down from the sweep for the bag and on the diamonds
Club Stick	20 link dog chains	20 link dog chains

Table 2. Species sampled by common and scientific names.

Common Name	Scientific Name
Invertebrates	
Sea Scallop	*Placopecten magellanicus*
Flatfish	
Yellowtail Flounder	*Limanda ferruginea*
Winter Flounder	*Pseudopleuronectes americanus*
Windowpane Flounder	*Scophthalmus aquosus*
Summer Flounder (Fluke)	*Paralichthys dentatus*
4-spot Flounder	*Paralichthys oblongus*
American Plaice	*Hippoglossoides platessoides*
Grey Sole	*Glyptocephalus cynoglossus*
Roundfish	
Haddock	*Melanogrammus aeglefinus*
Atlantic Cod	*Gadus morhua*
Monkfish	*Lophius americanus*
Spiny Dogfish	*Squalus acanthias*
Skates	
Barndoor Skates	*Dipturus laevis*
Little Skates	*Leucoraja erinacea*
Winter Skates	*Leucoraja ocellata*

Table 3. Area swept analysis: Estimated area by month including number of stations in each area. Values for area are in km^2.

Year	Month		Estimated Area (km^2) WGB	EGB	*Total*
2012	May	Stations	33	43	*76*
		Area	1278.55	4077.36	*5355.91*
	June	Stations	31	45	*76*
		Area	1201.06	4267.01	*5468.07*
	August	Stations	31	44	*75*
		Area	1201.06	4172.18	*5373.25*
	September	Stations	31	44	*75*
		Area	1201.06	4172.18	*5373.25*
	November	Stations	32	44	*76*
		Area	1239.81	4172.18	*5411.99*
	December	Stations	31	44	*75*
		Area	1201.06	4172.18	*5373.25*
2013	January	Stations	30	44	*74*
		Area	1162.32	4172.18	*5334.50*
	March	Stations	31	44	*75*
		Area	1201.06	4172.18	*5373.25*
	Average	*Stations*	*31.25*	*44.00*	*75.25*
		Area	*1210.75*	*4172.18*	*5382.93*

Table 4. Total catches on WGB by month from May 2012 to March 2013. Catches from CFTDD and NB dredges combined. Abbreviations: scallops (Sc), yellowtail (YT), winter flounder (WF), windowpane (Wp), summer flounder (SF), monkfish (Mf), barndoor skate (Bd), unclassified skates (Skate).

Year	Month	Sc	YT	WF	Wp	SF	Mf	Bd	Skate
2012	May	606	150	89	150	63	86	24	7551
	June	672	83	163	61	69	430	75	8710
	August	514	103	227	335	43	295	150	5486
	September	277	17	128	423	56	48	138	5793
	November	155	35	238	563	34	148	101	5491
	December	119	47	147	375	2	63	30	4260
2013	January	116	26	32	329	0	23	4	4108
	March	77	14	12	163	0	6	1	2061
Total		2535	475	1036	2399	267	1099	523	43460

Table 5. Total catches on EGB by month from May 2012 to March 2013. Catches from CFTDD and NB dredges combined. Abbreviations: scallops (Sc), yellowtail (YT), winter flounder (WF), windowpane (Wp), summer flounder (SF), monkfish (Mf), barndoor skate (Bd), unclassified skates (Skate).

Year	Month	Sc	YT	WF	Wp	SF	MF	BD	Skate
2012	May	638	456	11	462	68	159	124	3844
	June	531	218	2	11	1	176	137	2924
	August	432	686	18	1	7	351	201	3990
	September	568	1351	46	71	19	261	378	6479
	November	358	951	34	448	32	185	188	5335
	December	292	594	22	632	61	64	171	4554
2013	January	320	577	12	2765	14	32	79	8055
	March	265	134	9	1214	3	12	28	7771
Total		3404	4967	154	5604	205	1240	1306	42952

Table 6. Bottom water temperature on WGB by station from May 2012 through March 2013.

Station	Depth (m)	May '12	June '12	Aug '12	Sep '12	Nov '12	Dec '12	Jan '13	Mar '13
101	71	8.5	9.4	10.0	12.1	8.3	11.3	7.2	5.6
102	70	8.7	9.6	10.7	11.5	8.3	8.5	7.6	5.7
103	65	9.0	10.4	14.0	11.1	8.5	11.0	7.2	5.7
104	63	8.9	11.7	12.5	13.6	8.3	11.6	7.1	5.7
105	65	8.7	9.1	12.4	13.3	8.4	11.3	7.4	5.8
106	60	8.9	10.2	13.4	13.1	8.4	11.2	7.3	5.7
109	78	8.0	7.6	8.8	11.6	7.8	11.2	7.3	5.9
110	65	8.2	9.6	12.1	15.4	8.0	12.0	7.1	6.0
111	61	8.7	11.6	13.9	17.3	8.8	11.8	7.2	5.9
112	57	9.0	12.5	14.5	17.7	9.5	11.9	7.2	5.7
115	85	7.5	10.6	10.6	8.9	7.9	10.3	7.2	6.5
116	70	8.1	12.5	11.5	10.3	8.0	11.0	7.1	5.5
117	66	8.5	12.5	14.1	13.2	9.0	8.3	7.1	6.0
118	58	8.9	12.5	14.8	16.2	9.9	11.8	6.9	5.9
119	58	8.9	12.7	15.8	17.1	10.6	11.8	7.0	5.9
122	75	7.8	11.7	11.9	14.5	10.9	12.3	7.4	6.2
123	65	8.0	12.0	14.1	15.6	11.7	12.7	7.2	6.0
124	61	8.4	11.7	14.9	17.2	12.8	12.3	7.2	6.0
125	60	8.5	12.0	14.8	17.4	15.3	12.5	7.1	6.0
126	57	8.6	12.2	15.4	17.6	15.3	13.0	7.1	5.9
127	54	9.0	12.3	15.5	17.7	15.3	12.3	7.2	5.8
128	49	9.1	12.6	15.9	17.5	15.3	12.4	7.3	5.9
129	45	9.1	12.9	16.1	17.5	15.8	12.4	7.2	5.9
131	61	8.6	12.4	13.8	16.9	15.2	12.6	7.0	6.1
132	58	9.0	12.6	15.4	16.8	15.6	12.7	7.3	5.9
133	59	9.0	12.6	15.6	17.2	15.7	12.6	7.3	5.9
134	52	8.9	12.8	16.0	17.4	15.8	12.5	7.3	5.8
135	49	9.1	12.8	16.0	17.6	15.7	12.6	7.2	
136	46		12.9	15.9	17.3	15.9	12.4	7.2	5.9
137	65	8.5	12.3	12.8	16.3	15.5	12.6	6.9	6.3
138	67	8.6	12.3	13.0	16.4	15.4	10.3	7.1	6.2
Average		8.6	11.6	13.8	15.3	11.8	11.7	7.2	5.9

Table 7. Bottom water temperature on EGB by station from May 2012 through March 2013.

Station	Depth (m)	May '12	June '12	Aug '12	Sep '12	Nov '12	Dec '12	Jan '13	Mar '13
204	61	8.4	11.1	12.7	15.7	13.9	11.1	6.8	6.6
205	64	8.3	10.7	12.2	13.8	13.3	10.7	6.9	7.1
206	64	8.1	10.6	12.3	14.0	12.7	10.4	7.0	7.4
207	74	8.0	10.5	12.0	12.7	12.2	10.4	7.1	7.5
211	61	8.3	10.2	10.8	15.4	13.3	10.6	6.9	6.7
212	64	8.2	10.2	10.8	15.0	12.8	10.4	6.9	7.1
213	68	8.2	9.5	10.9	12.6	12.5	10.4	7.1	7.5
214	77	8.0	9.1	11.0	12.2	11.6	10.4	7.1	7.7
215	81	7.9	9.2	9.9	12.0	11.5	10.4	7.2	7.9
219	62	8.3	9.9	10.5	13.9	13.3	10.6	6.9	7.4
220	65	8.2	9.7	9.6	12.2	13.1	10.5	6.9	7.8
221	69	8.0	9.6	9.9	12.1	12.5	10.4	7.1	7.9
222	72	8.0	9.3	9.7	11.9	12.0	10.4	7.2	8.1
223	82	7.9	9.0	9.6	11.5	11.7	10.4	7.3	8.8
225	52	8.4	10.6	12.7	15.9	14.8	11.0	6.7	6.3
226	56	8.3	10.7	11.4	14.8	14.7	10.8	6.8	7.0
227	60	8.3	9.9	10.1	14.3	14.7	10.7	6.8	7.5
228	63	8.2	9.7	9.6	12.5	13.6	10.5	6.9	7.7
229	66	7.9	9.6	9.6	12.8	13.0	10.3	7.0	7.7
230	68	8.0	9.5	9.8	12.0	12.9	10.4	7.2	7.7
231	75	7.9	8.9	9.6	11.6	12.5	10.3	7.3	8.4
232	84	7.8	9.1	9.7	12.0	11.8	10.4	7.4	9.0
233	59	8.1	10.2	10.8	14.9	14.5	10.7	6.7	7.3
234	57	8.2	10.3	10.7	14.6	13.3	10.7	6.9	7.5
235	61	8.1	10.1	9.8	14.4	13.2	10.7	7.0	7.7
236	65	7.8	10.1	9.5	13.9	12.4	10.5	7.0	8.1
237	67	7.8	9.7	9.7	12.8	12.0	10.4	7.0	8.1
238	71	7.8	9.1	9.5	12.5	11.4	10.4	7.2	8.0
239	76	7.6	9.1	9.5	12.3	11.4	10.4	7.4	8.4
240	83	7.6	10.6	9.8	12.4	11.3	10.5	8.7	9.1
273	65	8.1	10.7	10.6	14.4	14.3	10.8	6.3	6.5
274	67	7.8	10.5	10.1	13.9	14.1	10.8	6.4	7.1
275	70	7.9	10.6	10.0	14.0	14.0	10.7	6.7	7.5
276	71	8.0	10.2	9.5	13.8	13.7	10.6	6.9	7.7
277	70	7.9	9.8	9.5	13.9	13.1	10.4	7.0	8.0
278	66	7.9	9.5	9.7	13.1	12.7	10.4	7.0	8.1
279	73	7.9	9.2	9.7	13.2	12.3	10.4	7.1	8.1
286	74	7.4	11.0	9.6	13.5	14.2	10.7	6.3	7.3
287	78	7.4	10.7	9.6	13.3	14.4	10.6	6.6	7.3
288	79	7.9	10.0	9.6	13.4	14.4	10.5	7.1	8.1
289	81	7.9	9.1	9.4	14.2	14.3	10.5	6.9	8.3
290	82	8.2	9.4	9.4	15.4	13.0	10.7	7.1	8.2
291	84	8.0	8.8	9.4	15.4	12.9	10.5	8.5	8.3
292	85	8.2	9.9	9.9	13.8	13.4	11.0	12.3	8.3
Average		8.0	9.9	10.2	13.5	13.1	10.6	7.1	7.7

Table 8. Yellowtail flounder bycatch rates by dredge type on WGB (top) and EGB (bottom) from May 2012 to March 2013.

WGB							
		CFTDD			NB		
Year	Month	YT (lbs)	Sc (lbs)	Bycatch Rate	YT (lbs)	Sc (lbs)	Bycatch Rate
2012	May	73	1959	0.04	79	2318	0.03
	June	42	2419	0.02	41	2531	0.02
	August	46	1727	0.03	52	1614	0.03
	September	8	833	0.01	8	657	0.01
	November	20	460	0.04	23	383	0.06
	December	23	311	0.07	34	270	0.13
2013	January	17	285	0.06	12	287	0.04
	March	8	232	0.04	6	262	0.02
Average				0.04			0.04
EGB							
2012	May	233	2106	0.11	206	2790	0.07
	June	108	1844	0.06	107	2166	0.05
	August	353	1604	0.22	417	1706	0.24
	September	676	1772	0.38	809	2053	0.39
	November	552	1227	0.45	504	1198	0.42
	December	241	880	0.27	422	1010	0.42
2013	January	329	1112	0.30	367	1137	0.32
	March	51	915	0.06	98	1088	0.09
Average				0.23			0.25

Table 9. Winter flounder bycatch rates by dredge type on WGB (top) and EGB (bottom) from May 2012 to March 2013.

WGB							
		CFTDD			NB		
Year	Month	WF (lbs)	Sc (lbs)	Bycatch Rate	WF (lbs)	Sc (lbs)	Bycatch Rate
2012	May	46	1959	0.02	105	2318	0.05
	June	143	2419	0.06	200	2531	0.08
	August	175	1727	0.10	282	1614	0.17
	September	121	833	0.15	124	657	0.19
	November	294	460	0.64	238	383	0.62
	December	130	311	0.42	129	270	0.48
2013	January	28	285	0.10	25	287	0.09
	March	7	232	0.03	13	262	0.05
Average				0.19			0.22
EGB							
2012	May	12	2106	0.01	15	2790	0.01
	June	3	1844	0.00	3	2166	0.00
	August	22	1604	0.01	29	1706	0.02
	September	50	1772	0.03	46	2053	0.02
	November	40	1227	0.03	41	1198	0.03
	December	34	880	0.04	25	1010	0.02
2013	January	19	1112	0.02	13	1137	0.01
	March	7	915	0.01	15	1088	0.01
Average				0.02			0.02

Table 10. Windowpane flounder bycatch rates by dredge type on WGB (top) and EGB (bottom) from May 2012 to March 2013.

WGB							
		CFTDD			NB		
Year	Month	Wp (lbs)	Sc (lbs)	Bycatch Rate	Wp (lbs)	Sc (lbs)	Bycatch Rate
2012	May	30	1959	0.02	44	2318	0.02
	June	15	2419	0.01	15	2531	0.01
	August	69	1727	0.04	102	1614	0.06
	September	122	833	0.15	100	657	0.15
	November	136	460	0.30	145	383	0.38
	December	98	311	0.32	108	270	0.40
2013	January	75	285	0.26	102	287	0.35
	March	40	232	0.17	45	262	0.17
Average				0.16			0.19
EGB							
2012	May	107	2106	0.05	130	2790	0.05
	June	3	1844	0.00	4	2166	0.00
	August	0	1604	0.00	0	1706	0.00
	September	22	1772	0.01	20	2053	0.01
	November	108	1227	0.09	134	1198	0.11
	December	144	880	0.16	223	1010	0.22
2013	January	758	1112	0.68	805	1137	0.71
	March	282	915	0.31	397	1088	0.37
Average				0.16			0.18

Table 11. Summer flounder bycatch rates by dredge type on WGB (top) and EGB (bottom) from May 2012 to March 2013.

WGB							
		CFTDD			NB		
Year	Month	SF (lbs)	Sc (lbs)	Bycatch Rate	SF (lbs)	Sc (lbs)	Bycatch Rate
2012	May	60	1959	0.03	48	2318	0.02
	June	128	2419	0.05	168	2531	0.07
	August	54	1727	0.03	180	1614	0.11
	September	132	833	0.16	141	657	0.21
	November	59	460	0.13	45	383	0.12
	December	0	311	0.00	14	270	0.05
2013	January	0	285	0.00	0	287	0.00
	March	0	232	0.00	0	262	0.00
Average				0.05			0.07
EGB							
2012	May	107	2106	0.05	155	2790	0.06
	June	0	1844	0.00	3	2166	0.00
	August	16	1604	0.01	33	1706	0.02
	September	49	1772	0.03	51	2053	0.02
	November	94	1227	0.08	72	1198	0.06
	December	150	880	0.17	79	1010	0.08
2013	January	20	1112	0.02	14	1137	0.01
	March	8	915	0.01	8	1088	0.01
Average				0.05			0.03

Table 12. Monkfish bycatch rates by dredge type on WGB (top) and EGB (bottom) from May 2012 to March 2013.

WGB							
		CFTDD			NB		
Year	Month	MF (lbs)	Sc (lbs)	Bycatch Rate	MF (lbs)	Sc (lbs)	Bycatch Rate
2012	May	92	1959	0.05	179	2318	0.08
	June	889	2419	0.37	840	2531	0.33
	August	693	1727	0.40	617	1614	0.38
	September	96	833	0.11	110	657	0.17
	November	396	460	0.86	360	383	0.94
	December	182	311	0.58	163	270	0.60
2013	January	92	285	0.32	36	287	0.13
	March	11	232	0.05	19	262	0.07
Average				0.34			0.34
EGB							
2012	May	377	2106	0.18	604	2790	0.22
	June	1012	1844	0.55	759	2166	0.35
	August	1417	1604	0.88	1429	1706	0.84
	September	1118	1772	0.63	1213	2053	0.59
	November	796	1227	0.65	770	1198	0.64
	December	427	880	0.49	270	1010	0.27
2013	January	84	1112	0.11	125	1137	0.11
	March	57	915	0.06	12	1088	0.01
Average				0.44			0.38

Table 13. Barndoor bycatch rates by dredge type on WGB (top) and EGB (bottom) from May 2012 to March 2013.

WGB							
		CFTDD			NB		
Year	Month	BD (lbs)	Sc (lbs)	Bycatch Rate	BD (lbs)	Sc (lbs)	Bycatch Rate
2012	May	9	1959	0.00	32	2318	0.01
	June	211	2419	0.09	368	2531	0.15
	August	172	1727	0.10	226	1614	0.14
	September	245	833	0.29	410	657	0.62
	November	250	460	0.54	366	383	0.95
	December	15	311	0.05	41	270	0.15
2013	January	1	285	0.00	6	287	0.02
	March	0	232	0.00	0	262	0.00
Average				0.14			0.26
EGB							
2012	May	61	2106	0.03	63	2790	0.02
	June	366	1844	0.20	463	2166	0.21
	August	167	1604	0.10	339	1706	0.20
	September	584	1772	0.33	578	2053	0.28
	November	494	1227	0.40	375	1198	0.31
	December	203	880	0.23	363	1010	0.36
2013	January	62	1112	0.07	82	1137	0.07
	March	10	915	0.01	12	1088	0.01
Average				0.17			0.18

Table 14. Results from iterative model building. Model with the minimum AIC value is shown in bold. Fixed effects are shown to the right of the ~ symbol. This symbol separates the response (Meat Weight) from the predictor variables used in the analysis. Interaction terms are denoted with the factor1*factor2 nomenclature. For the models that included a random effect, this effect was always evaluated at the station level. The best model was also evaluated without a random effect to assess the impact of including a random effect in the model.

Fixed Effects	Random effect	AIC	BIC	-2 log Likelihood
Meat Weight ~Shell Height + Month + Location + Month * Location	**Intercept**	**19172**	**19238**	**19134**
Meat Weight ~Shell Height + Depth + Month + Shell Height *Month	Intercept	19173	19239	19135
Meat Weight ~ Shell Height + Month + Shell Height * Month	Intercept	19174	19236	19138
Meat Weight ~Shell Height + Depth + Month + Location + Month *Location	Intercept	19174	19243	19134
Meat Weight ~ Shell Height + Month	Intercept	19174	19213	19152
Meat Weight ~Shell Height + Month + Location + Shell Height * Location	Intercept	19175	19220	19149
Meat Weight ~Shell Height + Depth + Month + Location + Shell Height * Month	Intercept	19175	19244	19135
Meat Weight ~Shell Height + Month + Location + Shell Height * Month	Intercept	19175	19241	19137
Meat Weight ~Shell Height + Month + Location	Intercept	19176	19218	19152
Meat Weight ~Shell Height + Depth + Month + Shell Height * Depth	Intercept	19178	19223	19152
Meat Weight ~Shell Height + Depth + Month + Location + Depth *Location	Intercept	19179	19227	19151
Meat Weight ~Shell Height + Depth + Month + Location + Shell Height * Depth	Intercept	19180	19228	19152
Meat Weight ~Shell Height + Depth + Month + Location + Shell Height * Location	Intercept	19181	19230	19153
Meat Weight ~Shell Height + Depth + Month	Intercept	19184	19225	19160
Meat Weight ~Shell Height + Depth + Month + Location	Intercept	19185	19231	19159
Meat Weight ~Shell Height + Depth + Month + Depth *Month	Intercept	19189	19254	19151
Meat Weight ~Shell Height + Depth + Month + Location + Depth * Month	Intercept	19190	19259	19150
Meat Weight ~Shell Height + Depth + Location +	Intercept	19281	19305	19267

Shell Height * Location				
Meat Weight ~Shell Height + Location + Shell Height * Location	Intercept	19281	19302	19269
Meat Weight ~ Shell Height + Depth	Intercept	19283	19300	19273
Meat Weight ~ Shell Height	Intercept	19283	19297	19275
Meat Weight ~Shell Height + Depth + Shell Height * Depth	Intercept	19284	19305	19272
Meat Weight ~Shell Height + Depth + Location	Intercept	19285	19306	19273
Meat Weight ~ Shell Height + Location	Intercept	19285	19302	19275
Meat Weight ~Shell Height + Depth + Location + Depth * Location	Intercept	19285	19310	19271
Meat Weight ~Shell Height + Depth + Location + Shell Height * Depth	Intercept	19286	19310	19272
Meat Weight ~Shell Height + Month + Location + Month * Location	None	19557	19664	19521
Meat Weight ~ Depth	Intercept	21223	21570	21548
Meat Weight ~ Month	Intercept	21491	21525	21471
Meat Weight ~ Depth + Month	Intercept	21492	21531	21470
Meat Weight ~ Location + Month	Intercept	21493	21531	21471
Meat Weight ~ Location + Month + Location * Month	Intercept	21494	21556	21458
Meat Weight ~ Location + Depth + Month	Intercept	21494	21536	21470
Meat Weight ~ Location + Depth + Month + Location*Month	Intercept	21495	21560	21457
Meat Weight ~ Location + Depth + Month + Location*Depth	Intercept	21495	21540	21469
Meat Weight ~ Depth + Month + Depth * Month	Intercept	21501	21564	21465
Meat Weight ~ Location + Depth + Month + Depth * Month	Intercept	21503	21569	21465
Meat Weight ~ Location	Intercept	21556	21570	21548
Meat Weight ~ Depth + Location	Intercept	21558	21575	21548
Meat Weight ~ Depth + Location + Depth * Location	Intercept	21559	21580	21547

Table 15. Parameter estimates for the best model as described by minimum AIC value. For the categorical variables (Month, Location), differences within that category are relative to the value with a 0 parameter estimate (i.e. EGB and September). Similarly, p-values within a category are relative to that standard and not for the whole model. All included fixed effects with the exception of location were significant overall.

Effect	**Month**	**Location**	**Estimate**	**SE**	**DF**	**t-value**	**p-value**
Intercept			-7.928	0.190	220	-41.813	<.0001
Shell Height			2.331	0.038	2623	60.759	<.0001
Month	August		0.169	0.042	2623	4.048	<.0001
Month	December		0.012	0.043	2623	0.286	0.775
Month	January		0.080	0.042	2623	1.910	0.056
Month	June		0.185	0.042	2623	4.418	<.0001
Month	March		0.161	0.042	2623	3.845	<.0001
Month	May		0.189	0.043	2623	4.364	<.0001
Month	November		0.021	0.042	2623	0.509	0.611
Month	September		0.000				
Location		WGB	0.031	0.042	2623	0.741	0.458
Location		EGB	0.000				
Month*Location	August	WGB	-0.003	0.059	2623	-0.043	0.965
Month*Location	August	EGB	0.000				
Month*Location	December	WGB	-0.115	0.060	2623	-1.918	0.055
Month*Location	December	EGB	0.000				
Month*Location	January	WGB	-0.116	0.059	2623	-1.967	0.049
Month*Location	January	EGB	0.000				
Month*Location	June	WGB	0.091	0.059	2623	1.532	0.126
Month*Location	June	EGB	0.000				
Month*Location	March	WGB	-0.063	0.060	2623	-1.061	0.289
Month*Location	March	EGB	0.000				
Month*Location	May	WGB	0.037	0.060	2623	0.618	0.537
Month*Location	May	EGB	0.000				
Month*Location	November	WGB	-0.004	0.059	2623	-0.074	0.941
Month*Location	November	EGB	0.000				
Month*Location	September	WGB	0.000				
Month*Location	September	EGB	0.000				

Table 16. Minimum and maximum observed values for % moisture and protein content and the moisture:protein ratio in scallop adductor muscle (meat) per area and size class.

Area	SH Size Class (mm)	Min-Max % Moisture	Min-Max % Protein	Moisture:Protein Ratio
CA1	130	75.53-85.72	9.96-18.11	4.2-4.7
CA2	130	74.86-80.72	15.81-18.47	4.1-4.4
CA1	100-110	75.22-80.17	15.70-18.49	4.1-4.3
CA2	100-110	74.50-78.82	17.21-18.86	4.0-4.2
CA1N	>145	75.3-85.41	11.22-24.85	3.0-3.4
CA1S	>145	74.4-83.35	12.32-19.85	7.6-8.5
CA2	>145	75.27-86.7	10.32-19.23	3.9-4.5

Table 17. Length and sample size of yellowtail and winter flounder reproductively staged. Asterisk indicates the total includes the two fish with unknown sex due to infection.

Species	Sex	Size	Number	Total
Yellowtail Flounder	Female	38.63	1734	2279*
	Male	34.00	543	
Winter Flounder	Female	42.13	583	846
	Male	38.35	263	

Table 18. Female winter flounder maturity results for Western Georges Bank. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

WGB		Stages						
	Month	I	D	R	U	S	T	Total
2012	May	0	0	1	1	13	0	15
	June	0	0	0	0	78	20	98
	August	0	0	0	0	39	69	108
	September	0	9	0	0	0	6	15
	November	2	104	5	0	0	0	111
	December	0	69	1	0	0	0	70
2013	January	0	2	20	0	0	0	22
	March	0	2	2	4	0	0	8
	Totals	2	186	29	5	130	95	447

Table 19. Male winter flounder maturity results for Western Georges Bank. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

WGB		Stages						
	Month	I	D	R	U	S	T	Total
2012	May	0	0	0	3	0	0	3
	June	0	0	0	0	26	21	47
	August	1	0	0	0	3	49	53
	September	0	0	0	0	1	15	16
	November	0	54	2	0	0	1	57
	December	0	23	5	0	0	0	28
2013	January	0	0	8	0	0	0	8
	March	0	0	5	1	0	0	6
	Totals	1	77	20	4	30	86	218

Table 20. Female winter flounder maturity results for Eastern Georges Bank. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

EGB		Stages						
	Month	I	D	R	U	S	T	Total
2012	May	0	0	0	1	11	0	12
	June	0	0	0	0	2	0	2
	August	0	0	0	0	4	10	14
	September	0	1	0	0	0	2	3
	November	0	17	6	0	0	0	23
	December	0	20	0	0	0	1	21
2013	January	0	2	8	0	0	0	10
	March	0	0	2	2	0	0	4
	Totals	0	40	16	3	17	13	89

Table 21. Male winter flounder maturity results for Eastern Georges Bank. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

EGB		Stages						
	Month	I	D	R	U	S	T	Total
2012	May	0	0	0	1	0	0	1
	June	0	0	0	0	0	0	0
	August	0	0	0	0	1	3	4
	September	0	0	0	0	0	6	6
	November	0	10	0	0	0	1	11
	December	0	2	0	0	0	0	2
2013	January	0	0	2	0	0	0	2
	March	0	0	5	0	0	0	5
	Totals	0	12	7	1	1	10	31

Table 22. Catches of all fish sampled during the 2012 bycatch year broken into size classes and prevalence of confirmed cases of *Ichthyophonus*

	<31cm	31-36cm	37-42cm	>43cm
All females sampled	6	108	234	73
Females with *Ichthyophonus*	0	1	5	5
All males sampled	29	107	20	1
Males with *Ichthyophonus*	0	8	0	0

Table 23. Sensitivity of yellowtail flounder biomass estimates to the assumed catchability value of the NB dredge. WGB and EGB refer to area-swept yellowtail flounder biomass estimates for WGB and EGB respectively, while Total refers to the sum of both WGB and EGB. All biomass values are in metric tons (mt). Bold values indicate catchability value used for this report.

	Assumed catchability value									
	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	**0.201**	0.1
CAI	35.22	39.13	44.02	50.31	58.7	70.44	88.05	117.4	**174.94**	352.2
CAII	795.4	883.78	994.25	1136.29	1325.67	1590.81	1988.51	2651.34	**3950.72**	7954.03
Total	*830.62*	*922.91*	*1038.28*	*1186.6*	*1384.37*	*1661.25*	*2076.56*	*2768.74*	***4125.66***	*8306.23*

Table 24. Total catches in the NB dredge (control) of the F/V Liberty and F/V Celtic in September 2012. F/V Liberty tow parameters were 30 minutes and 4.8 kt, whereas F/V Celtic tow time was 15 minutes and tow speed was 4.0 kt.

	Liberty	Celtic
Scallops	424	125
Yellowtail	737	108
Winter	85	22
Windowpane	220	92
Summer	38	11
Monkfish	287	100
Barndoors	273	95

Table 25. Area-swept biomass estimates of yellowtail flounder for each survey trip. Area-swept biomass estimates derived from the bycatch survey were compared to rho-adjusted estimates of age 1+ yellowtail flounder biomass for 2012 from the most recent TRAC assessment.

Year	Month	WGB	EGB	Total	% Age 1+ Biomass from 2012 TRAC
2012	MAY '12	418.47	2445.14	2863.61	253%
	JUN '12	235.31	1276.37	1511.68	134%
	AUG '12	292.74	5079.61	5372.35	475%
	SEPT '12	36.90	7291.96	7328.85	648%
	NOV '12	107.58	5505.30	5612.88	496%
	DEC '12	213.68	4796.61	5010.29	443%
2013	JAN '13	57.24	3827.08	3884.32	343%
	MAR '13	37.56	1383.71	1421.27	126%
Average		*174.94*	*3950.72*	*4125.66*	*365%*

Table 26. Model building results for each species examined in the analysis. Fixed effects included in the model indicate the specification that resulted in the lowest AIC value for that particular species. Random effects are shown in brackets and were included at the station level. Species where the model failed to converge are indicated.

Species	**Model Specification**
Sea Scallops	RE_{CFTDD} ~ intercept + length + [station]
Yellowtail Flounder	RE_{CFTDD} ~ intercept +[station]
Blackback Flounder	RE_{CFTDD} ~ intercept +[station]
Windowpane Flounder	RE_{CFTDD} ~ intercept +[station]
Summer Flounder	Did not converge
Monkfish	RE_{CFTDD} ~ intercept +[station]
Barndoor Skate	RE_{CFTDD} ~ intercept + length + [station]
Unclassified Skates	RE_{CFTDD} ~ intercept +[station]

Table 27. Mixed effects model using the unpooled catch data. Results are for from the model that provided the best fit (intercept and length) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	**Effect**	**Estimate**	**SE**	**DF**	**t-value**	**p-value**	**LCI**	**UCI**
Sea Scallop	Intercept	0.720	0.068	7504	10.596	<0.001	0.587	0.853
	Length	-0.006	0.000	7504	-11.251	<0.001	-0.007	-0.005
Barndoor Skate	Intercept	0.231	0.135	1651	1.717	0.086	-0.033	0.495
	Length	-0.005	0.002	1651	-2.014	0.044	-0.009	-0.0001

Table 28. Mixed effects model using the pooled catch data. Results are for from the model that provided the best fit (intercept only) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale and the exp(Estimate) is the estimated relative efficiency on the probability scale. Percent change represents the average percentage change in the catch of the CFTDD relative to the NB dredge. Significant parameters are shown in bold.

Species	**Effect**	**Estimate**	**StdErr**	**DF**	**t value**	**p-value**	**LCI**	**UCI**	**exp(Est)**	**% Change**
Sea Scallop	Intercept	-0.013	0.019	602	-0.659	0.510	-0.051	0.025	0.987	-1.3%
Yellowtail Flounder	Intercept	-0.034	0.048	417	-0.711	0.478	-0.127	0.060	0.967	-3.3%
Winter Flounder	**Intercept**	**-0.183**	**0.065**	**254**	**-2.835**	**0.005**	**-0.311**	**-0.056**	**0.832**	**-16.8%**
Windowpane Flounder	**Intercept**	**-0.182**	**0.036**	**411**	**-5.020**	**>0.001**	**-0.254**	**-0.111**	**0.833**	**-16.7%**
Monkfish	Intercept	0.041	0.040	444	1.024	0.307	-0.038	0.120	1.042	4.2%
Barndoor Skate	Intercept	-0.019	0.052	391	-0.367	0.714	-0.122	0.083	0.981	-1.9%
Unclassified Skates	**Intercept**	**-0.086**	**0.022**	**606**	**-3.79**	**0.0002**	**-0.1306**	**-0.0414**	**0.917**	**-8.24%**

FIGURES

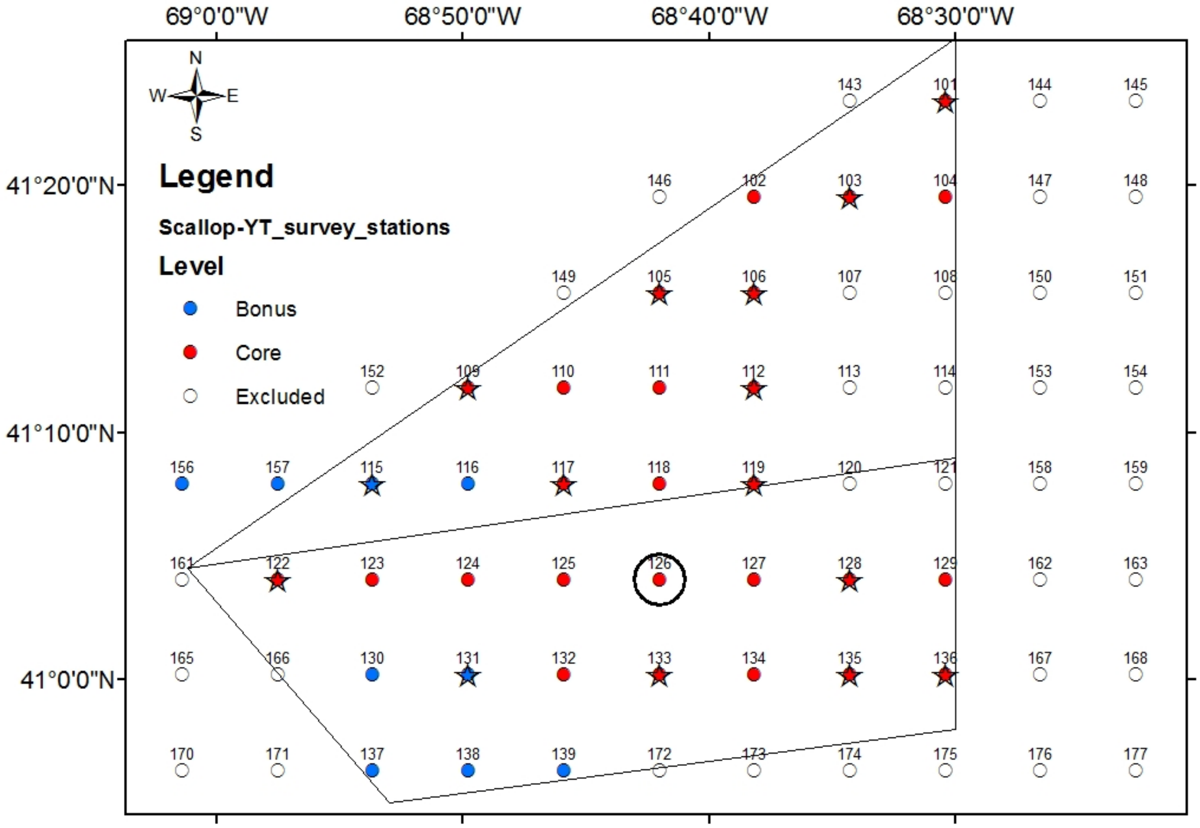


Figure 1. Map of 31 stations sampled on Western Georges Bank (WGB) (CA1-30 and CA1-39 were not consistently sampled). Core (red dots), bonus (blue dots), meat sampling (stars), and scallop energetics/reproductive sampling (circled) stations are shown. Stations are 5.39 km (2.9 nm) apart longitudinally and 7.18 km (3.9 nm) apart latitudinally. CA1-56 and CA1-57 were only sampled on the FV Celtic September 2012.

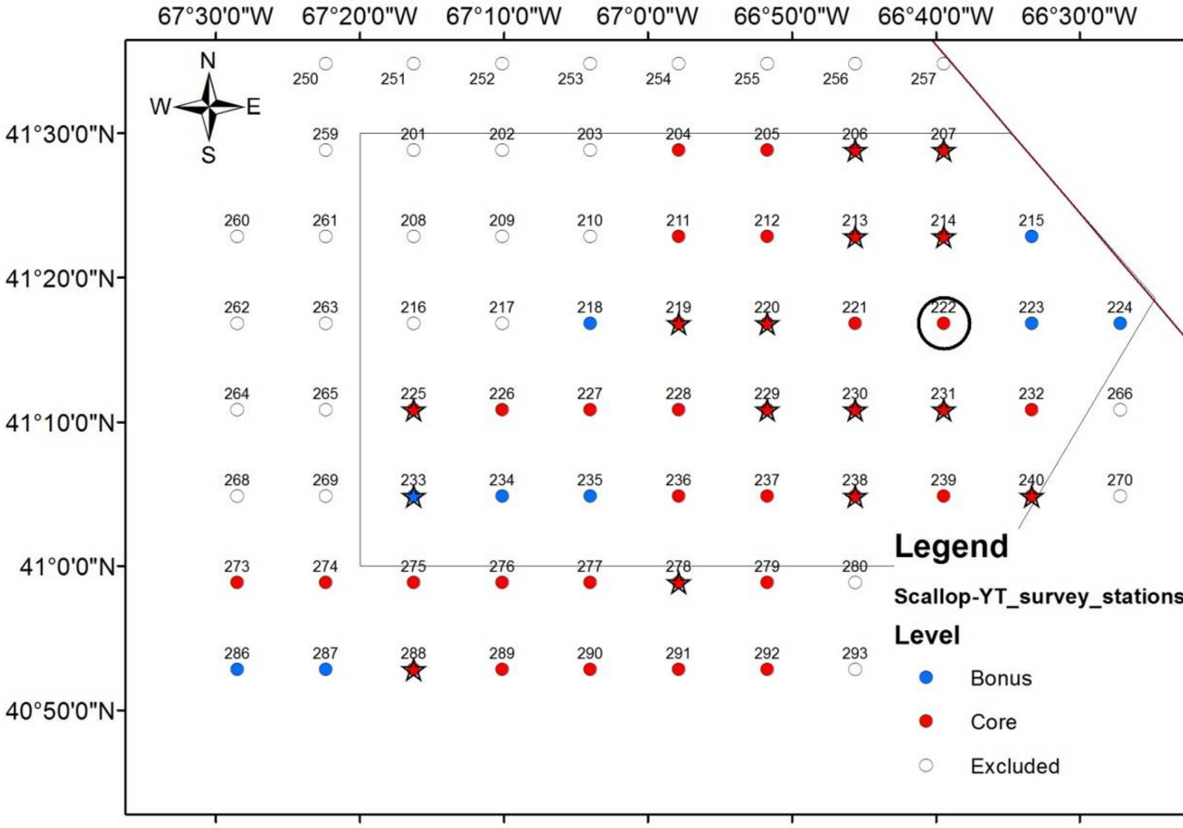


Figure 2. Map of 44 stations sampled on Eastern Georges Bank (EGB) (218 and 224 were not consistently sampled). Core (red dots), bonus (blue dots), meat sampling (stars), and scallop energetics/reproductive sampling (circled) stations are shown. Stations are 8.55 km (4.6 nm) apart longitudinally and 11.12 km (6.0 nm) apart latitudinally.

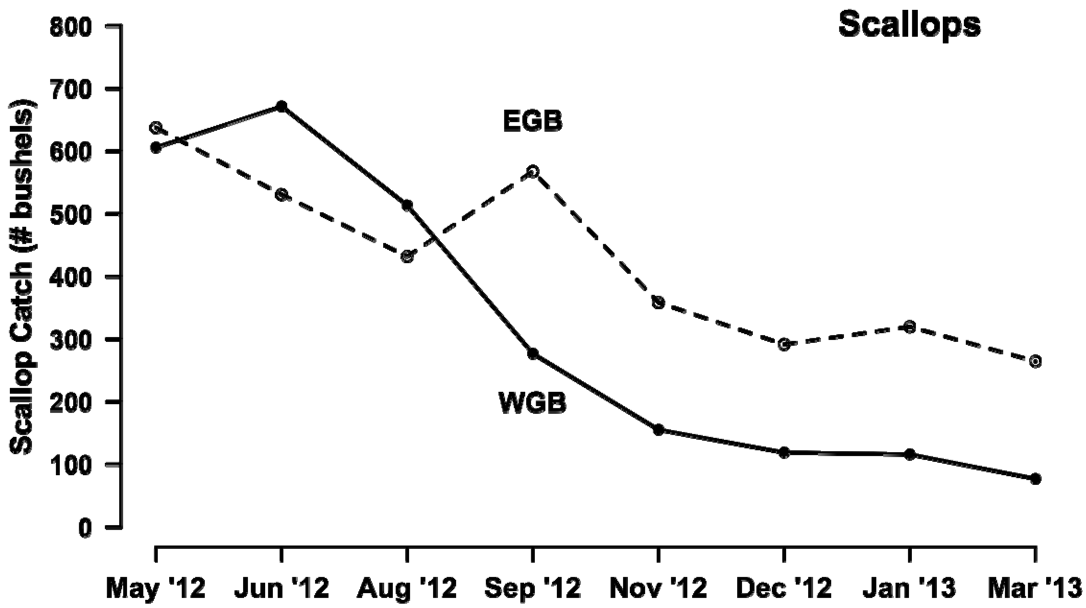


Figure 3. Scallop catch (# bushels) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

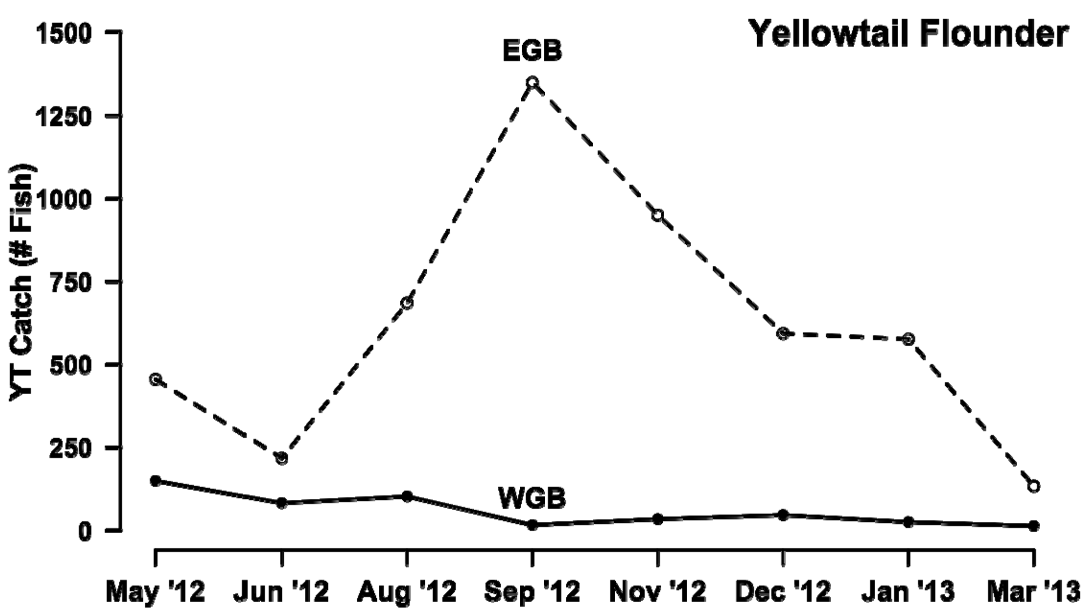


Figure 4. Yellowtail flounder catch (# fish) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

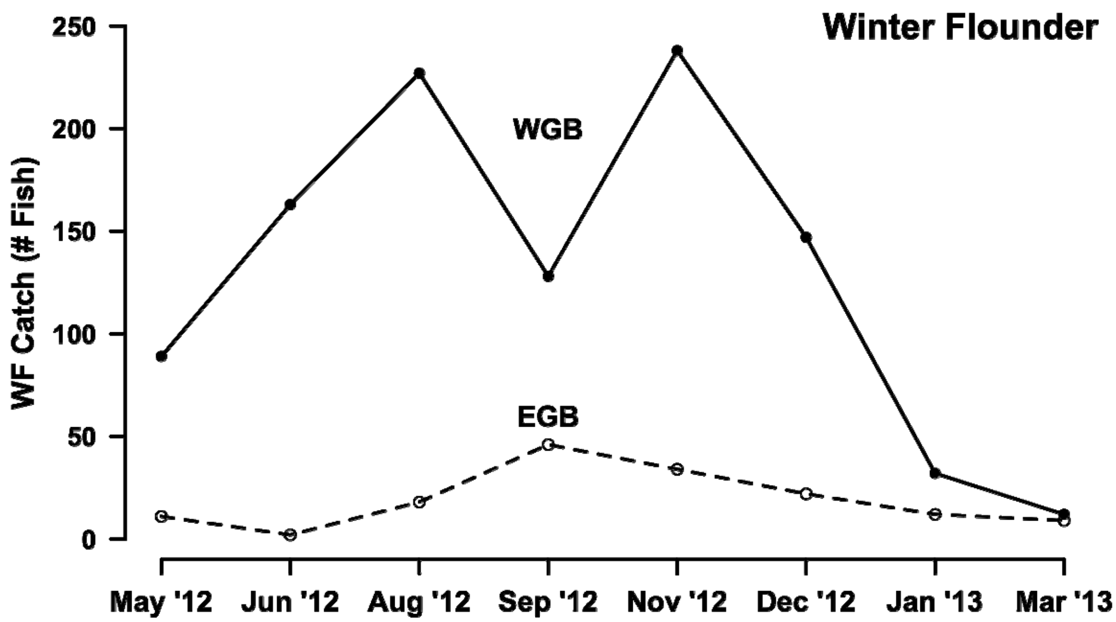


Figure 5. Winter flounder catch (# fish) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

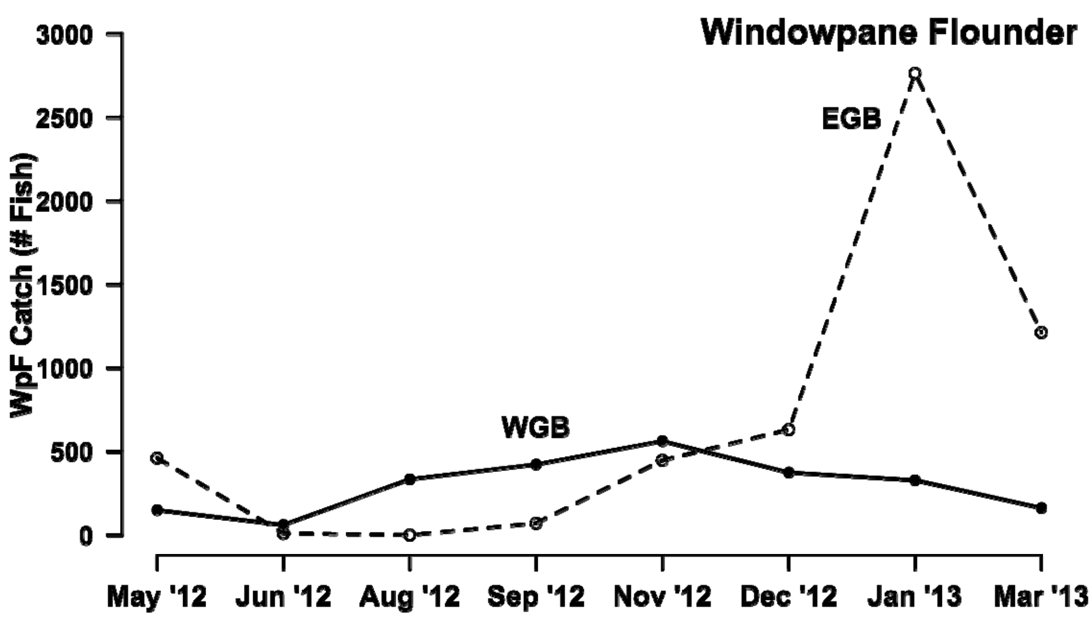


Figure 6. Windowpane flounder catch (# fish) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

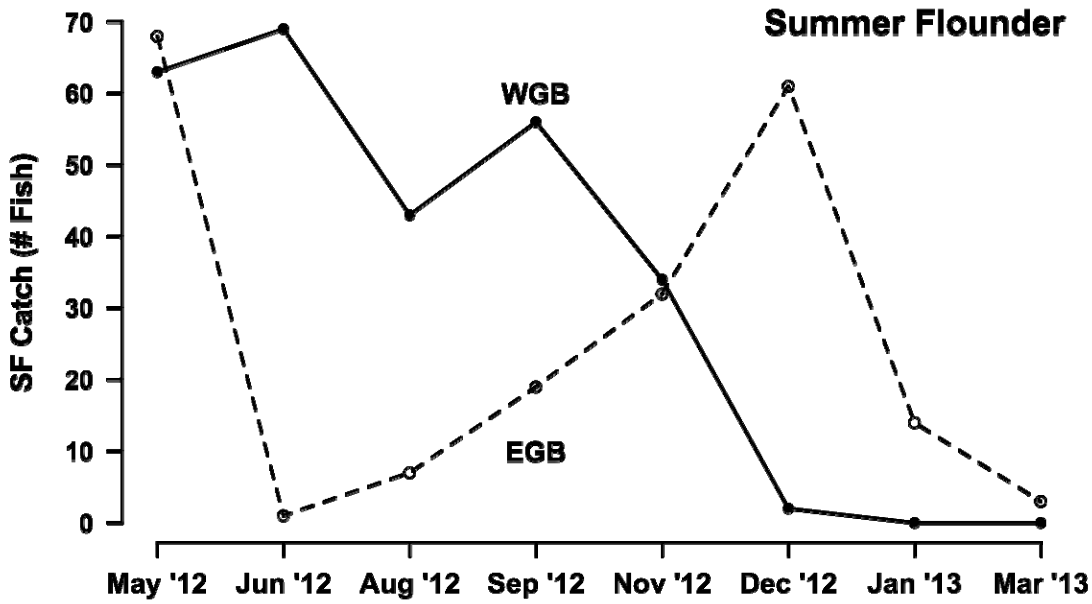


Figure 7. Summer flounder catch (# fish) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

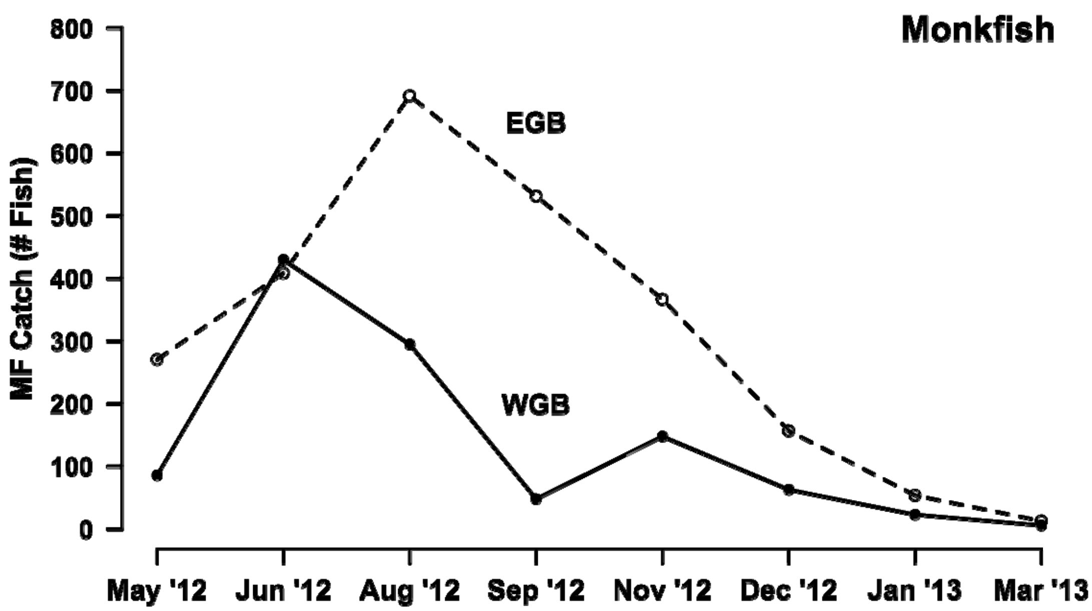


Figure 8. Monkfish catch (# fish) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

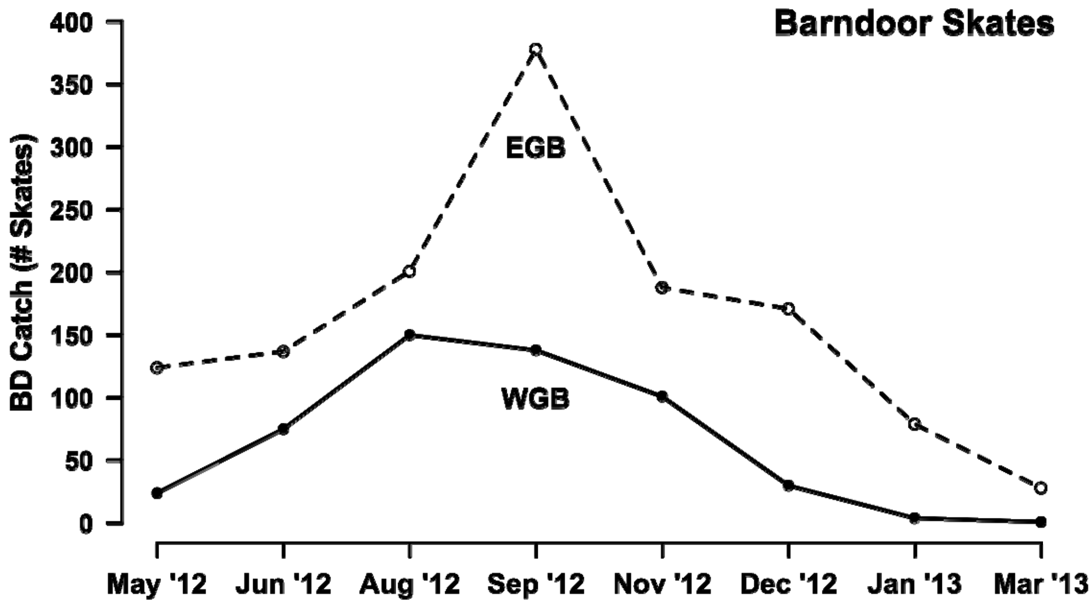


Figure 9. Barndoor skate catch (# skates) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

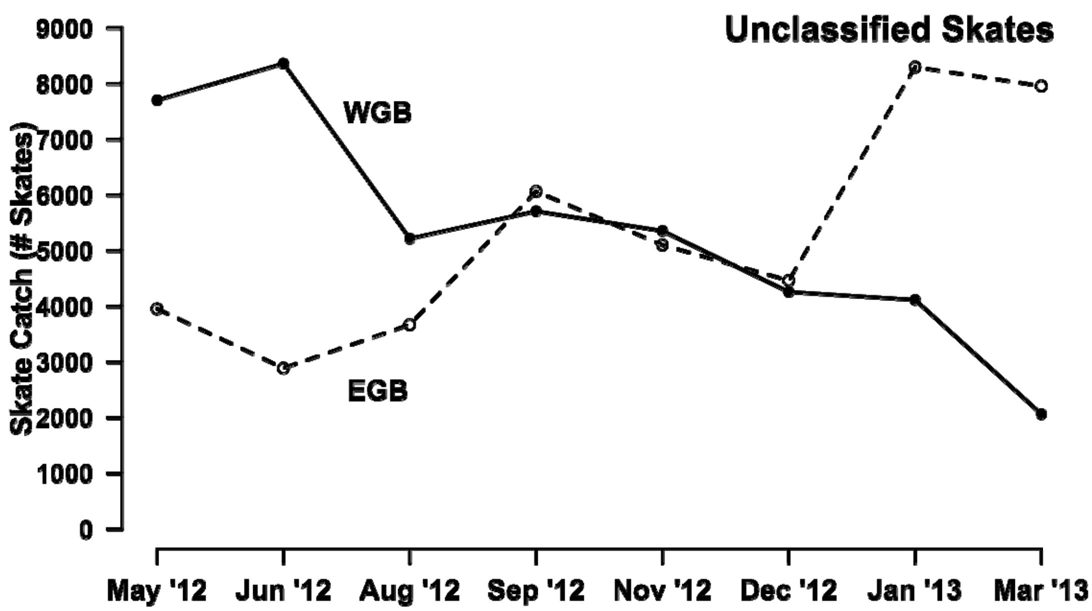


Figure 10. Unclassified skate catch (# skates) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) from May 2012 to March 2013.

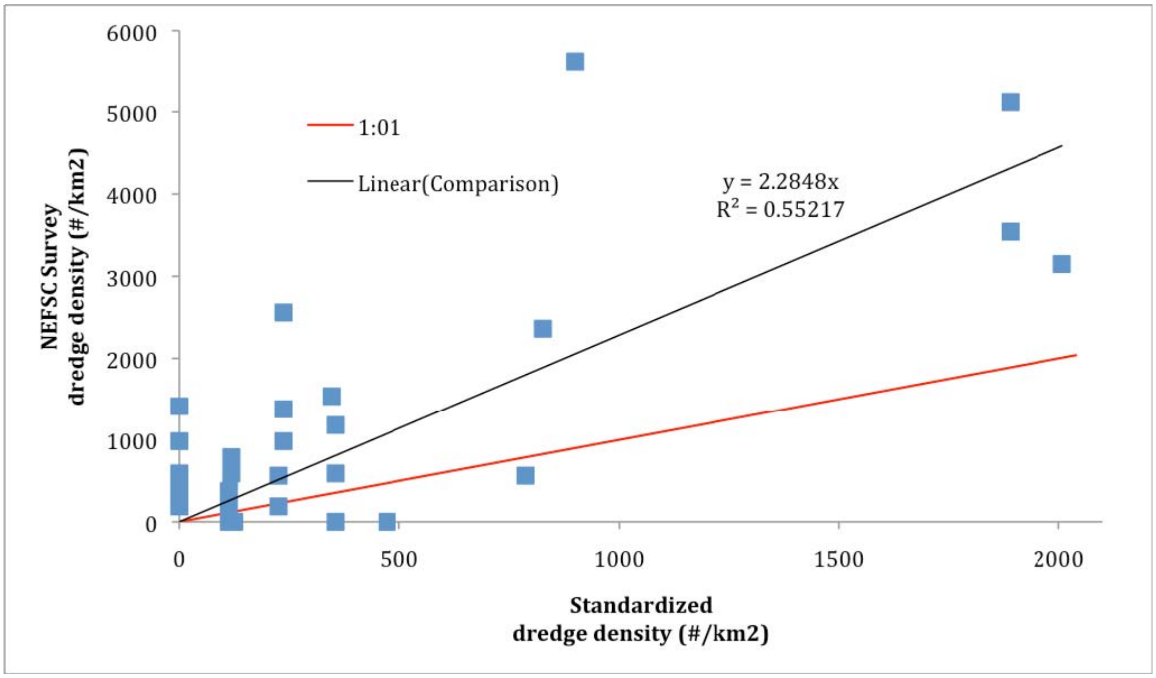


Figure 11. Comparison of yellowtail flounder density between dredges in September 2012. X-axis shows density of yellowtail flounder (#/km^2) for the NB dredge and the y-axis shows density of yellowtail flounder (#/km^2) for the NEFSC survey dredge. The red line indicates the 1:1 line and the solid black line indicates the linear regression through the origin with resulting slope and R^2 values.

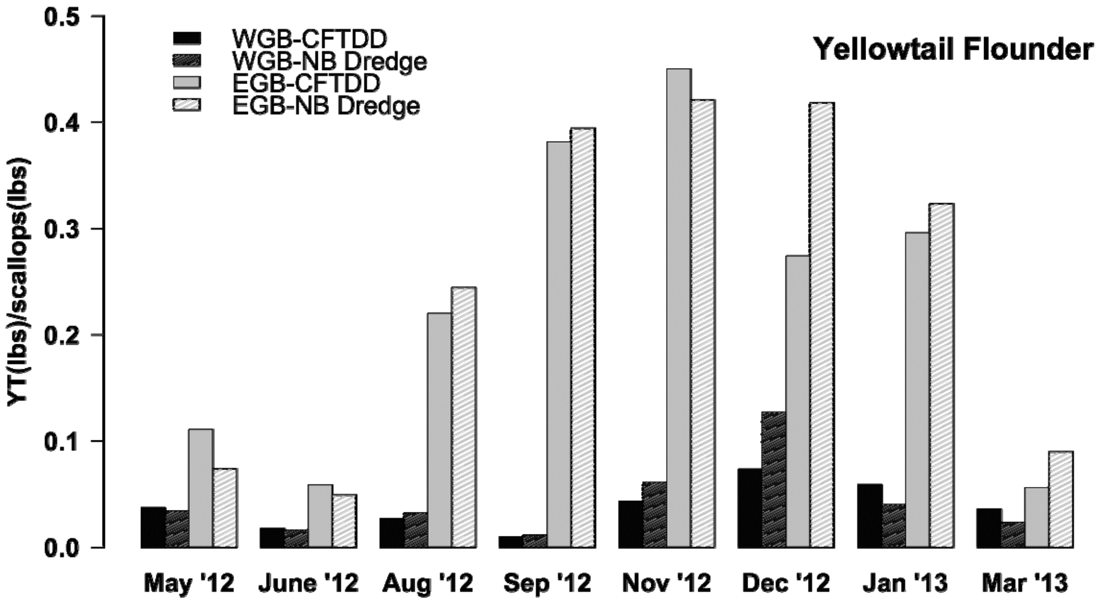


Figure 12. Yellowtail flounder bycatch rates (lbs of yellowtail/lbs of scallops) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) by dredge type from May 2012 to March 2013.

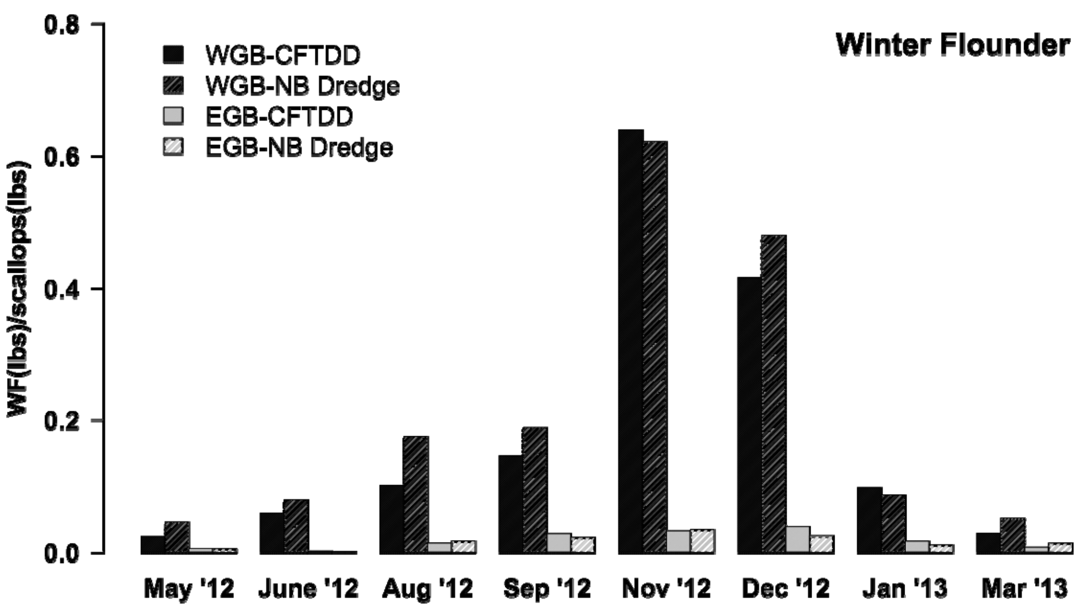


Figure 13. Winter flounder bycatch rates (lbs of winter/lbs of scallops) Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) by dredge type from May 2012 to March 2013.

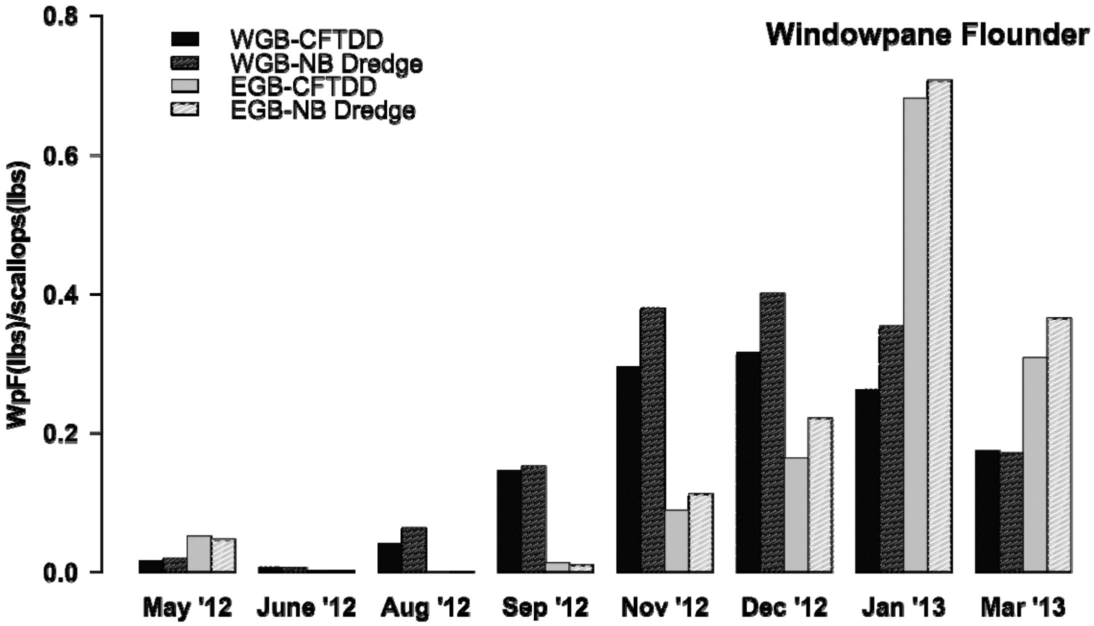


Figure 14. Windowpane flounder bycatch rates (lbs of windowpane/lbs of scallops) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) by dredge type from May 2012 to March 2013.

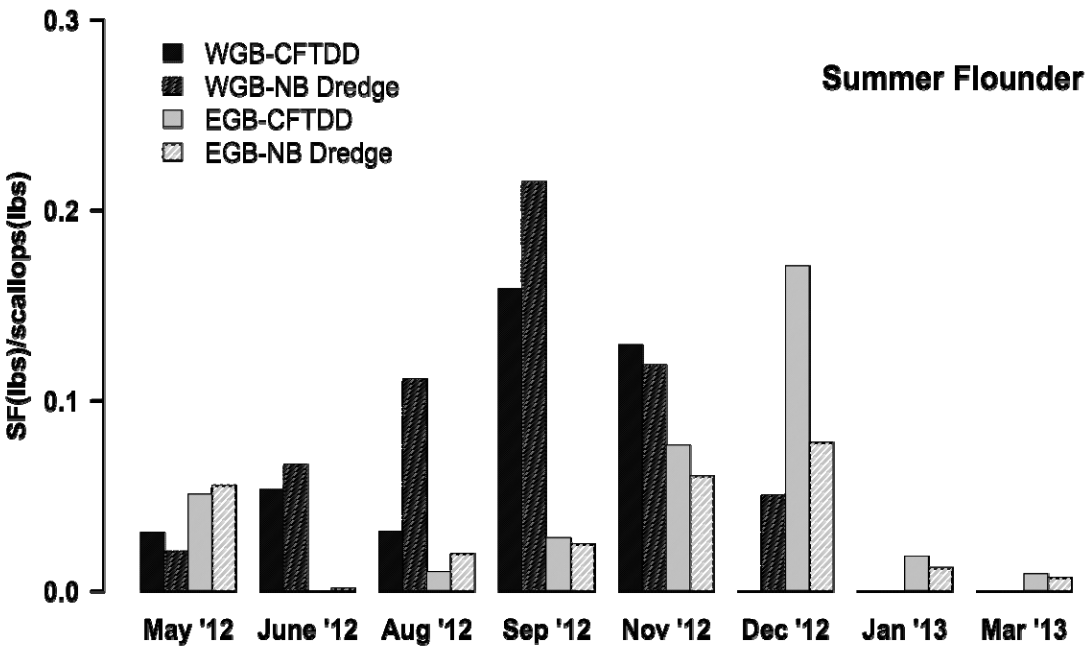


Figure 15. Summer flounder bycatch rates (lbs of summer/lbs of scallops) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) by dredge type from May 2012 to March 2013.

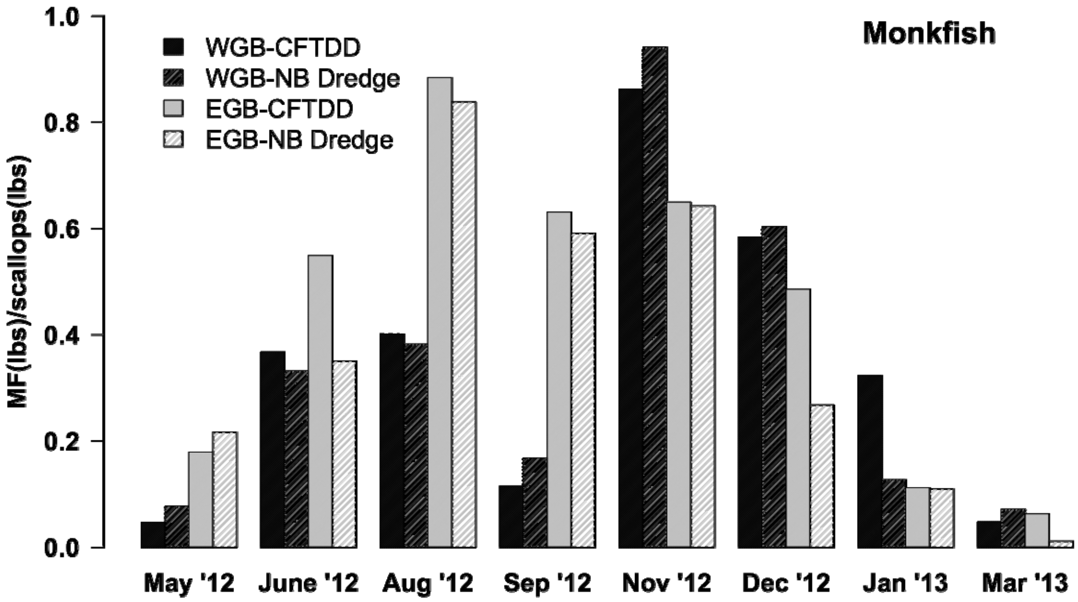


Figure 16. Monkfish bycatch rates (lbs of monkfish/lbs of scallops) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) type from May 2012 to March 2013.

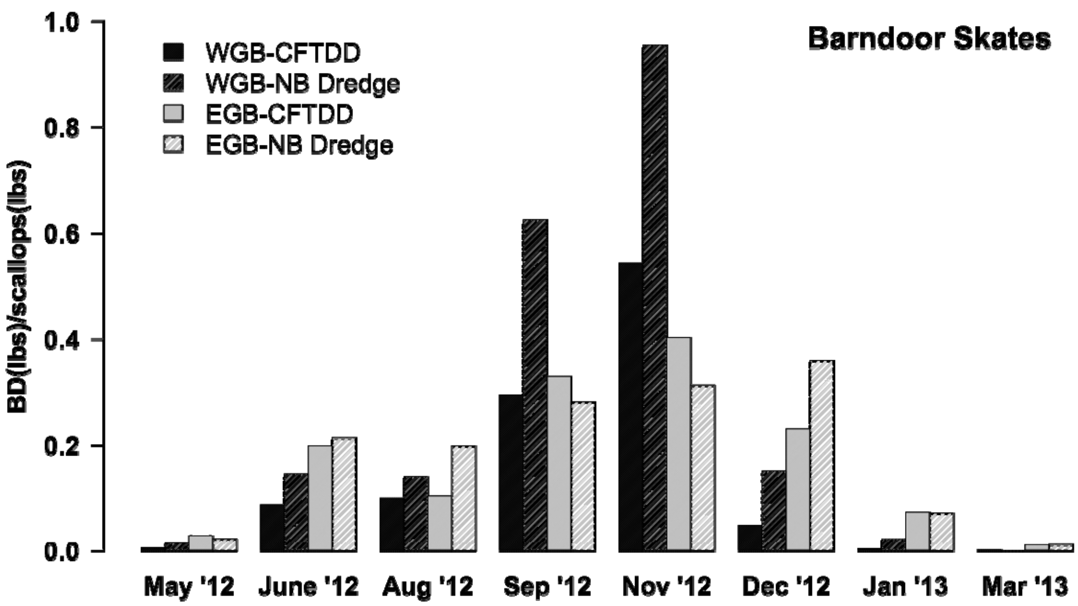


Figure 17. Barndoor skate bycatch rates (lbs of barndoor/lbs of scallops) on Western Georges Bank (WGB; 31 stations) and Eastern Georges Bank (EGB; 44 stations inside and outside of CAII) by dredge type from May 2012 to March 2013.

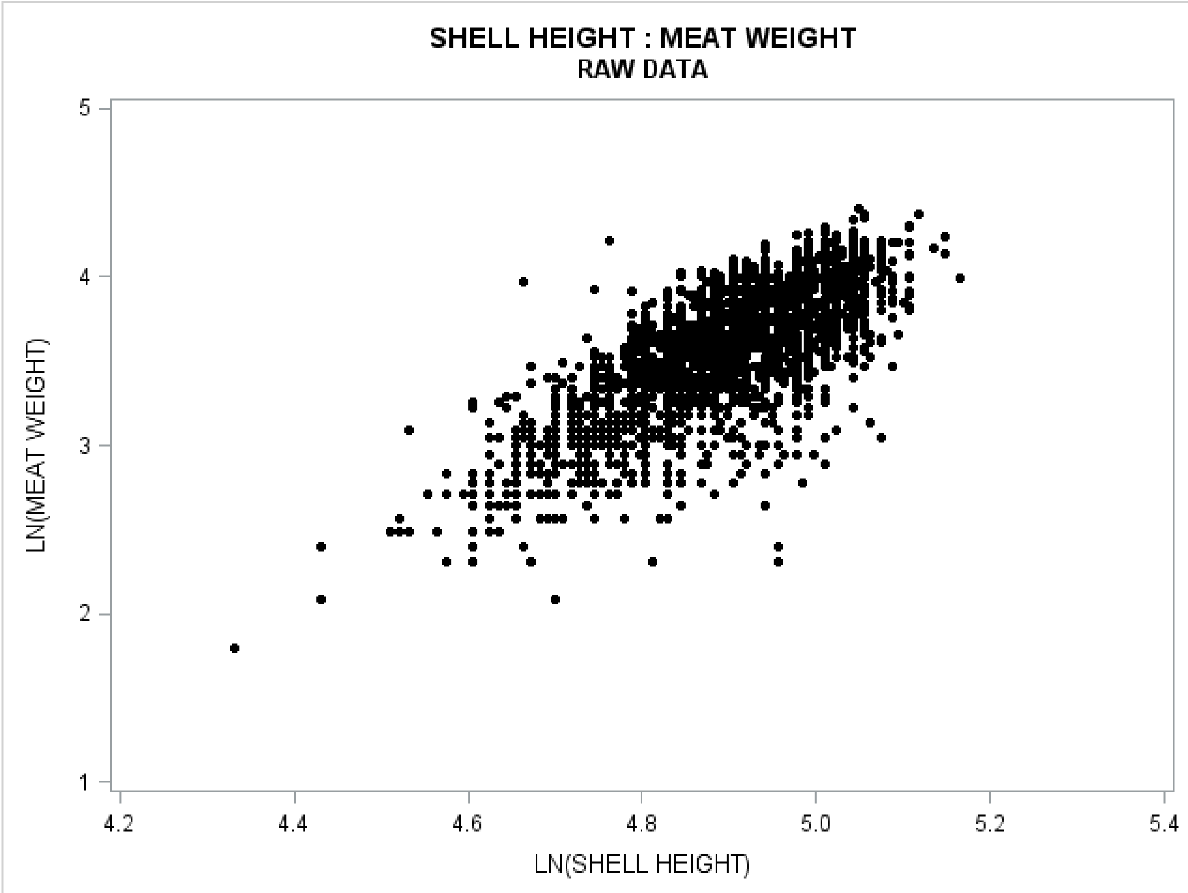


Figure 18. Shell height: meat weight data for all trips combined.

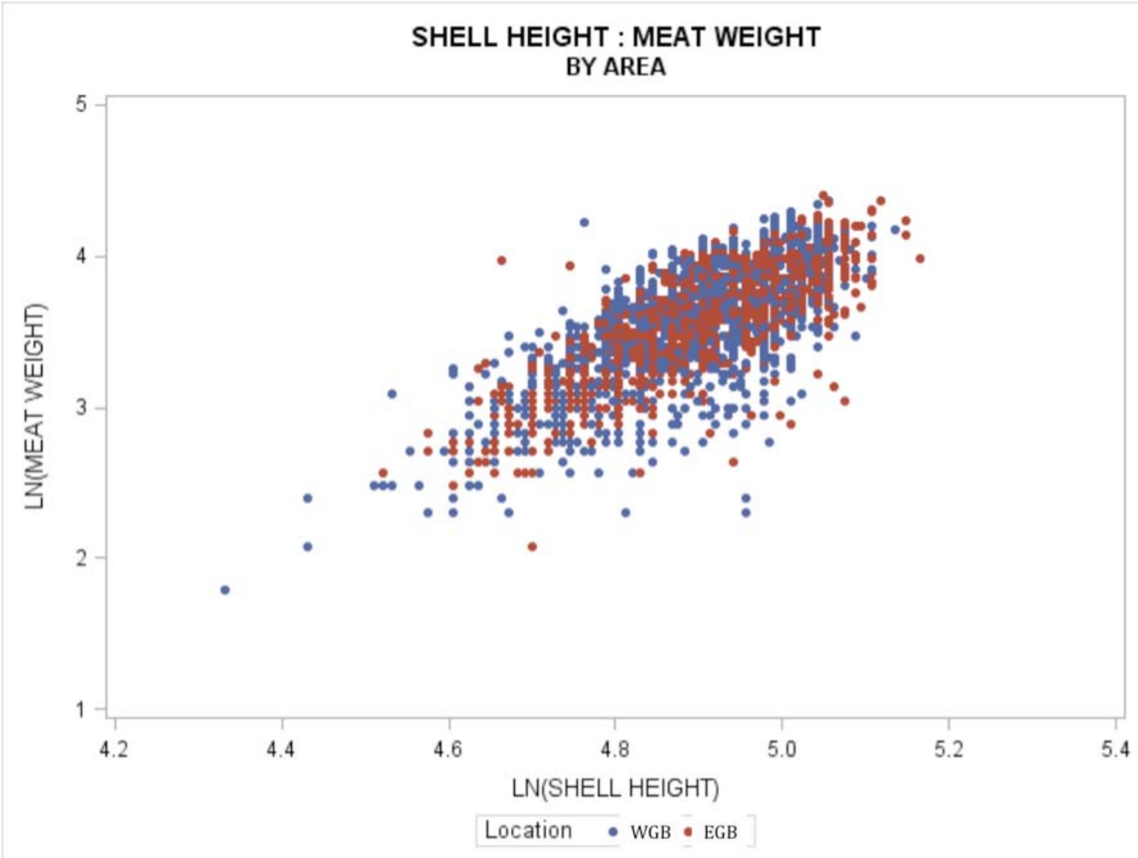


Figure 19. Shell Height : Meat Weight data for all trips combined delineated by area (Western and Eastern Georges Bank).

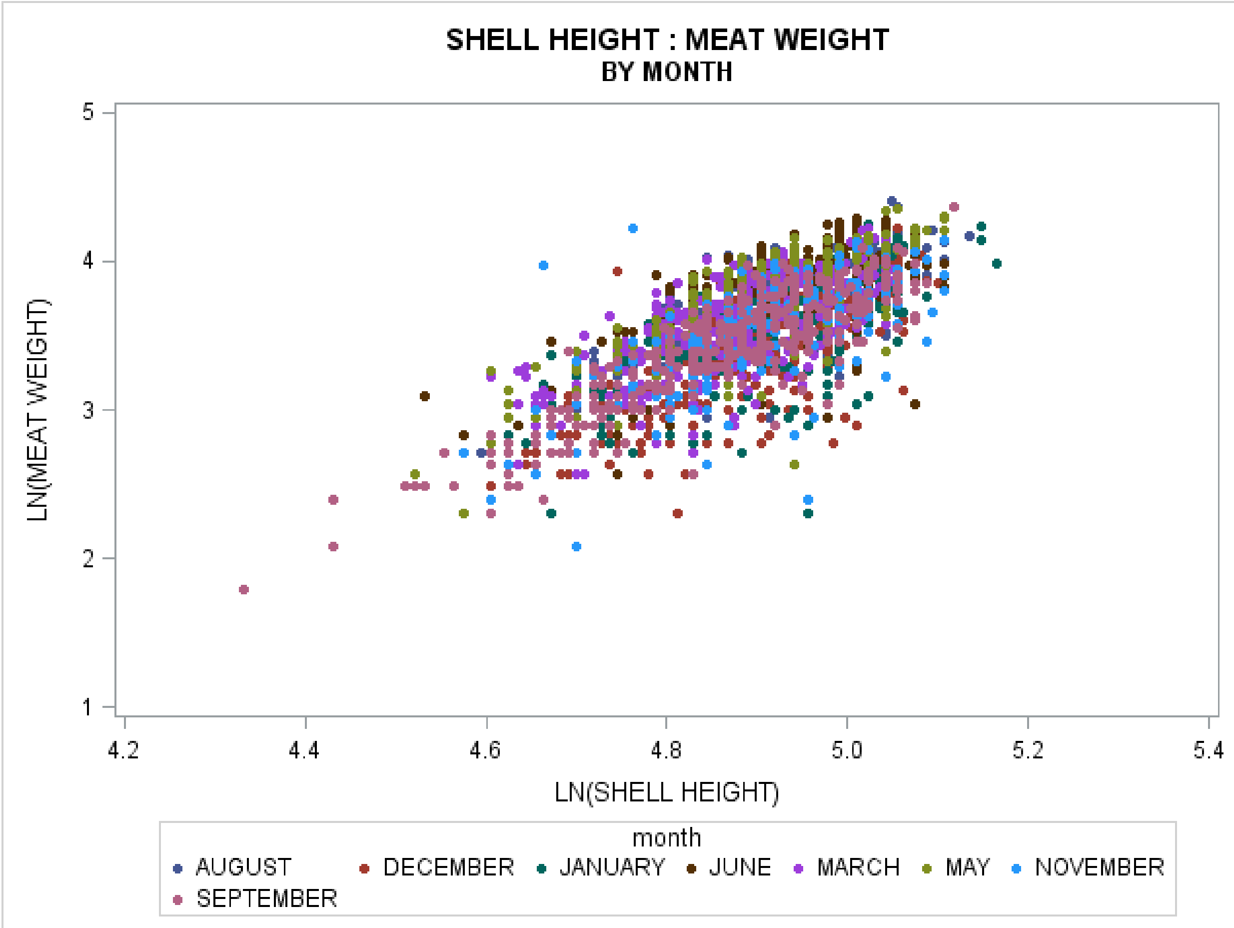


Figure 20. Shell Height:Meat Weight data for all trips combined delineated by sampling month.

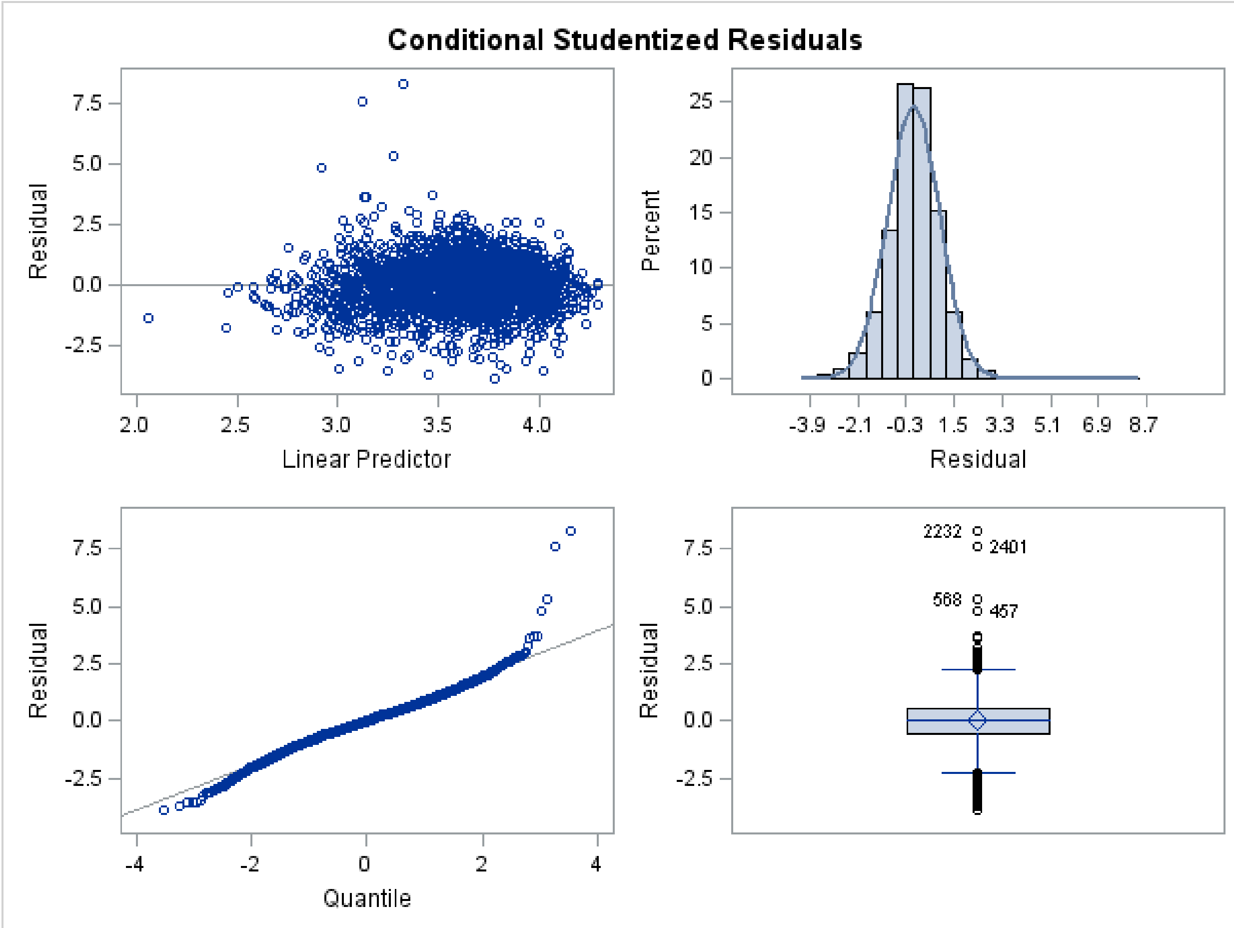


Figure 21. Residuals and QQ plot for the best model fit as determined by minimum AIC value. Residuals show no evidence of pattern, however a number of larger than expected meats were observed as evidenced by a small number of large positively valued residuals.

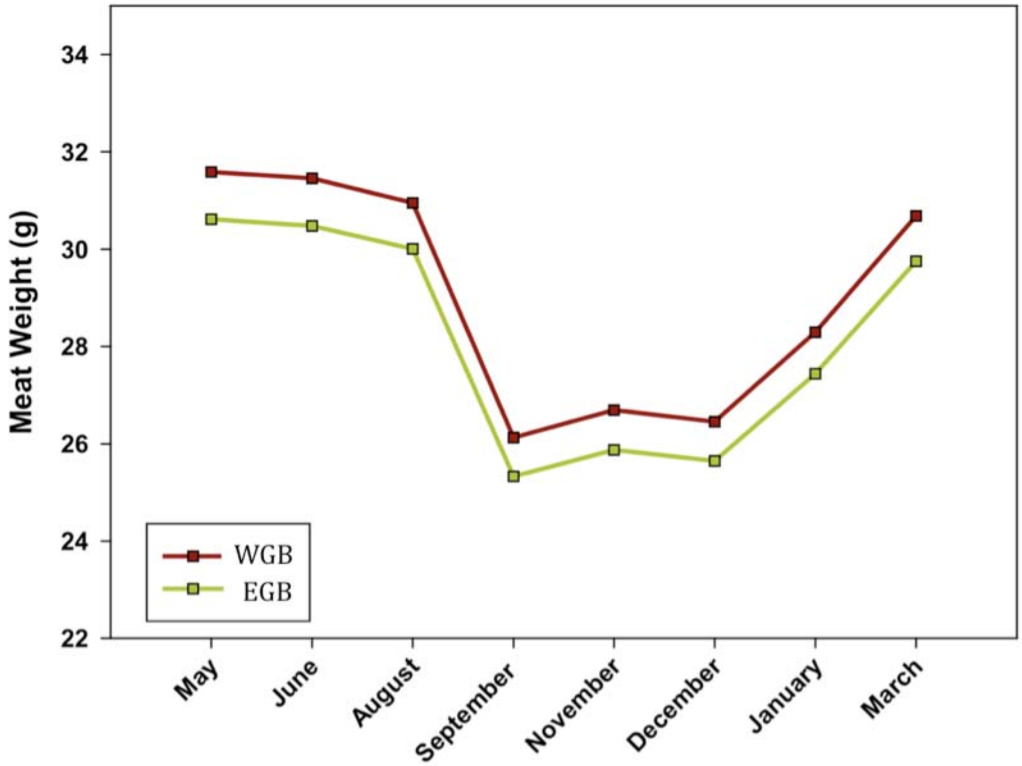


Figure 22. Predicted meat weight of a 120 mm shell height scallop from Western and Eastern Georges Bank from May 2012 - March 2013. Estimated meat weights were calculated from parameter estimates from the lowest AIC value model.

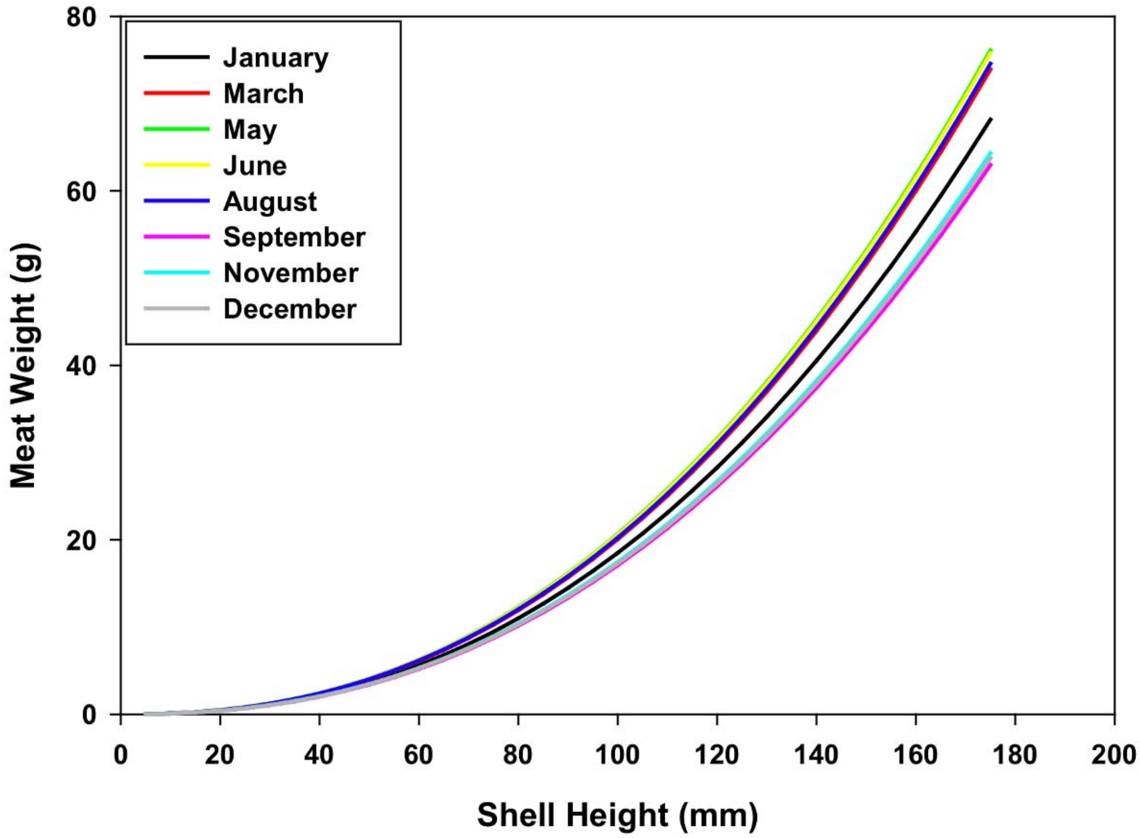


Figure 23. Comparison of estimated curves for each month on Western Georges Bank.

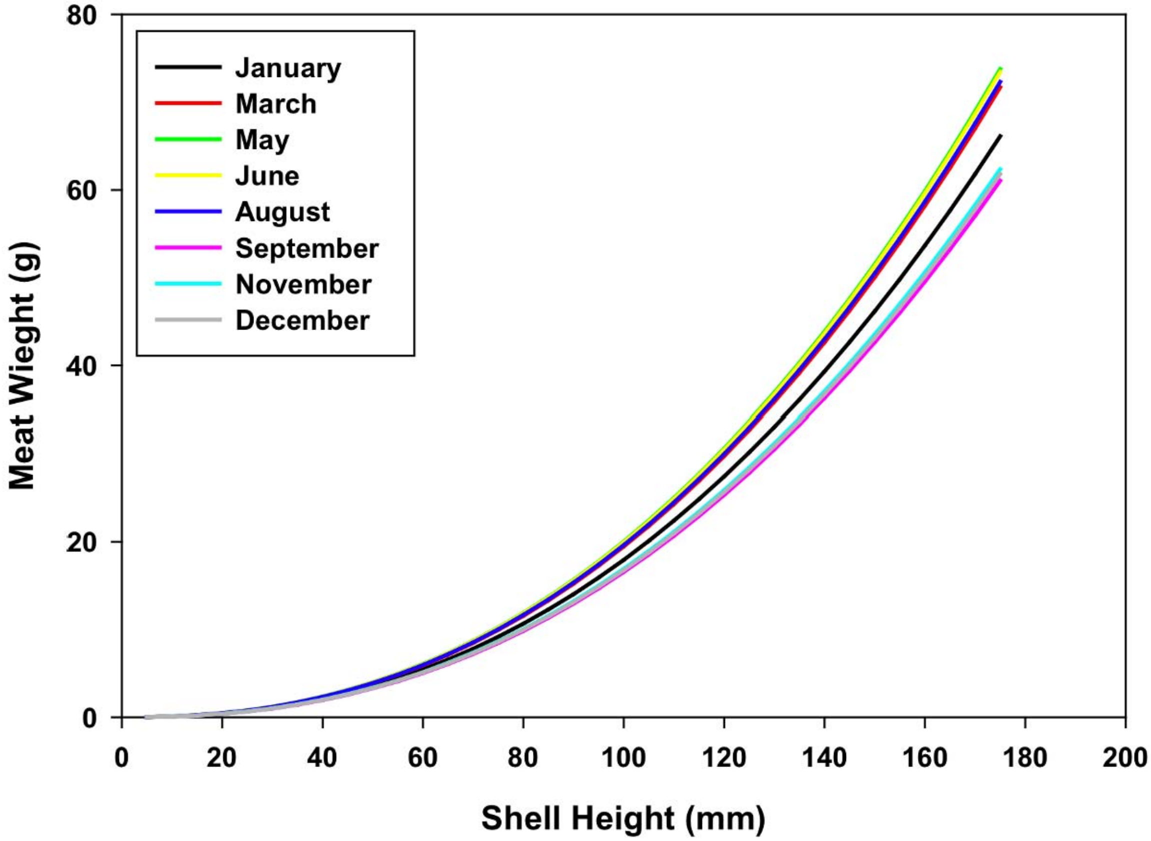


Figure 24. Comparison of estimated curves for each month on Eastern Georges Bank.

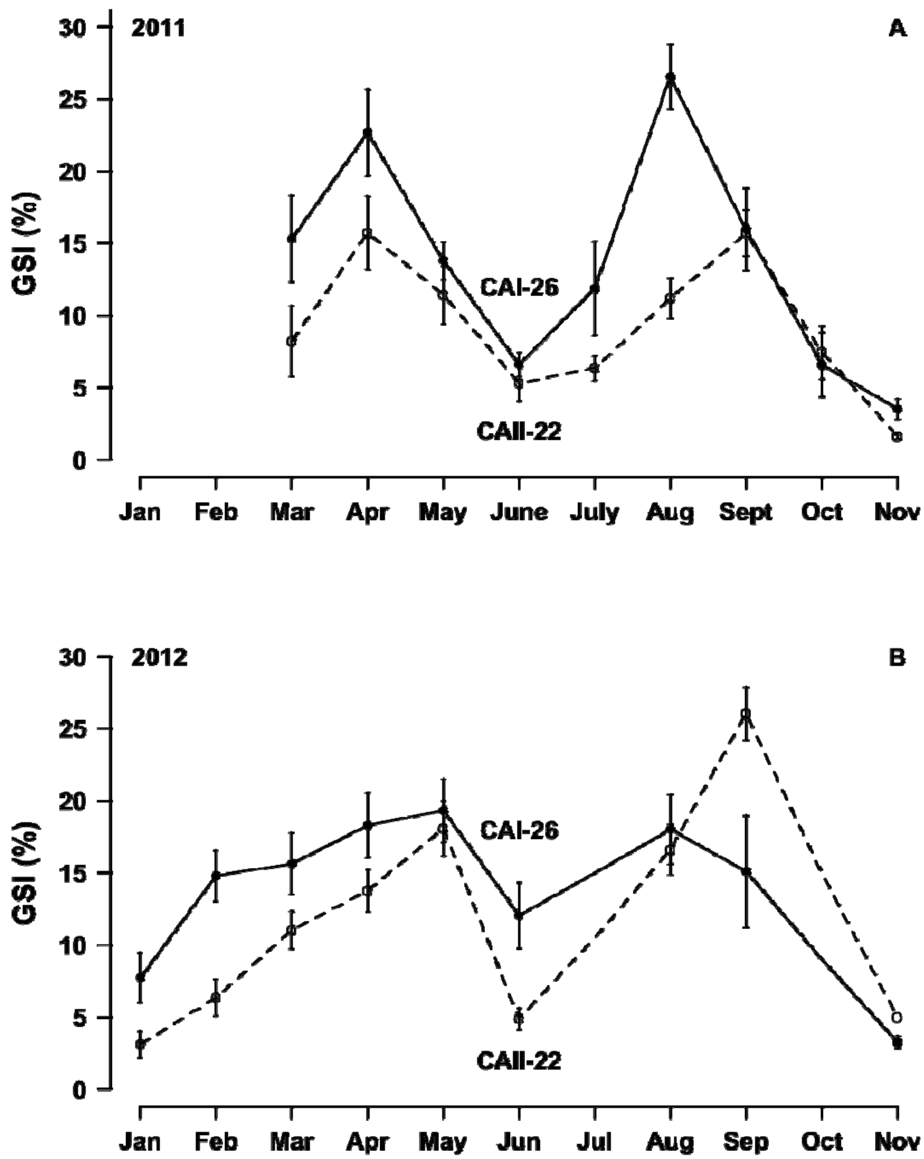


Figure 25. Mean dry gonosomatic index (GSI) in CAI-26 and CAII-22 in (A) 2011 and (B) 2012. Vertical lines represent 95% CI.

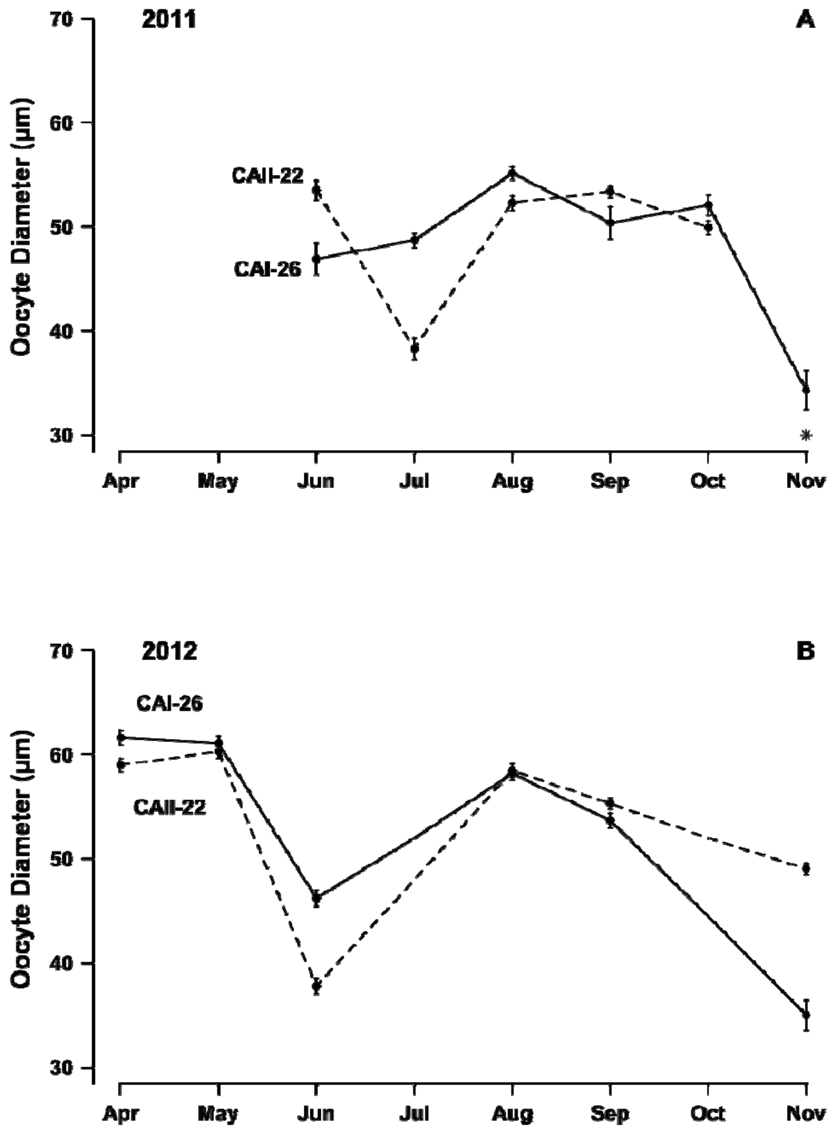


Figure 26. Mean oocyte diameter at CAI-26 and CAII-22 in (A) 2011 and (B) 2012. Vertical lines represent 95% CI. No oocytes were observed in November 2011 (asterisk).

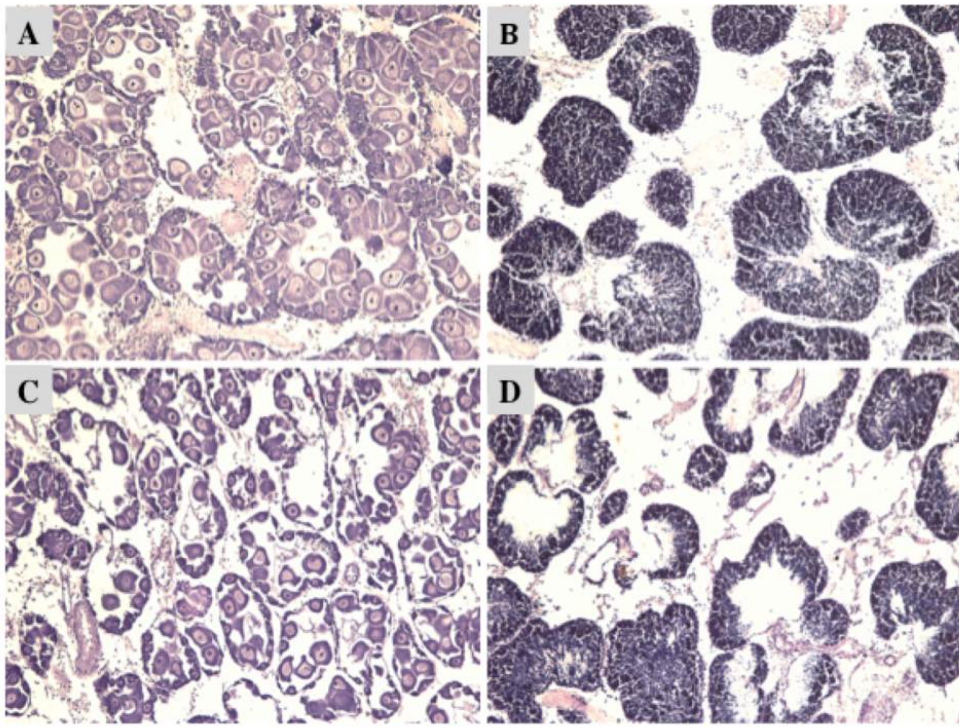
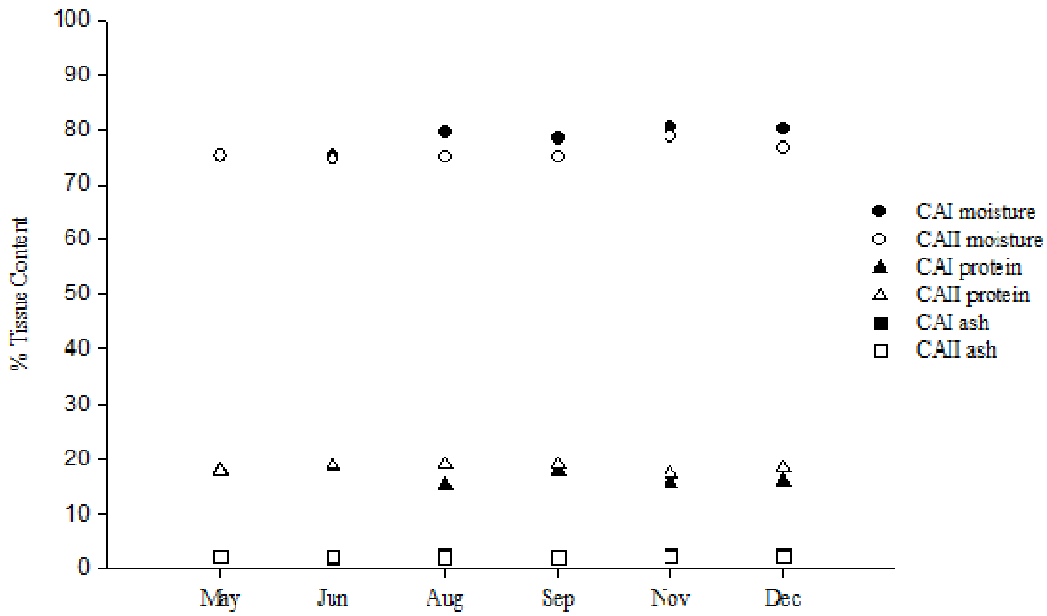


Figure 27. Histological Evidence of Spring Spawning CAI-26: A. 120 mm female (June), B. 125 mm male (June); CAII-22: C. 136 mm female (July), D. 155 mm male (June).



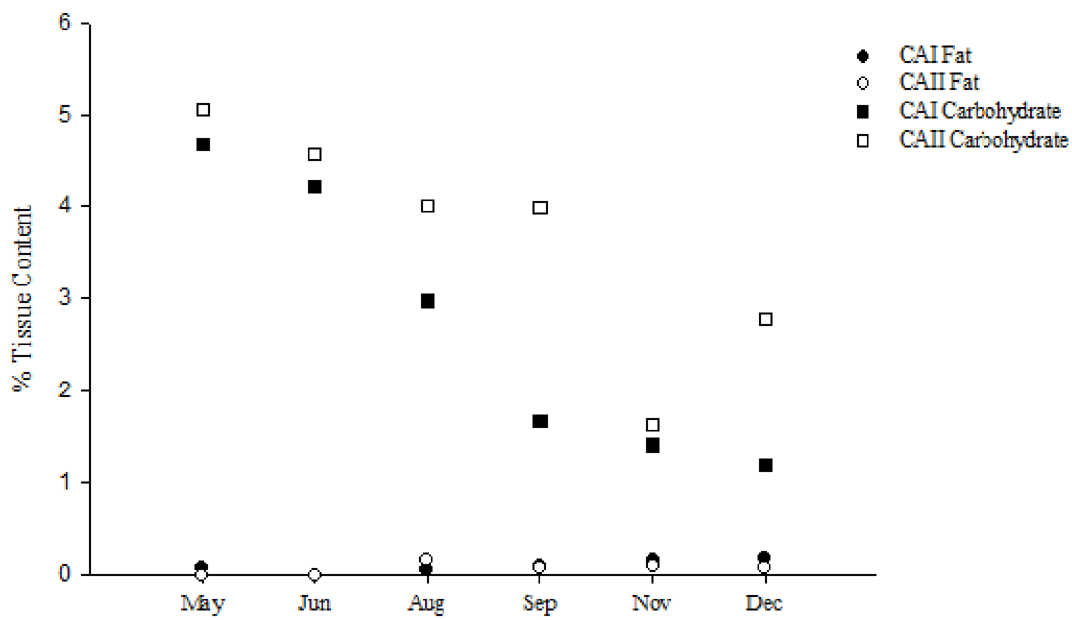


Figure 28. Proximate analysis of 100-110 mm SH scallops from CAI and CAII in 2012. The primary energy source is from carbohydrates. The mean % fat content is very low in both populations. Values represent the mean (± SD), n = 10 (pooled sample).

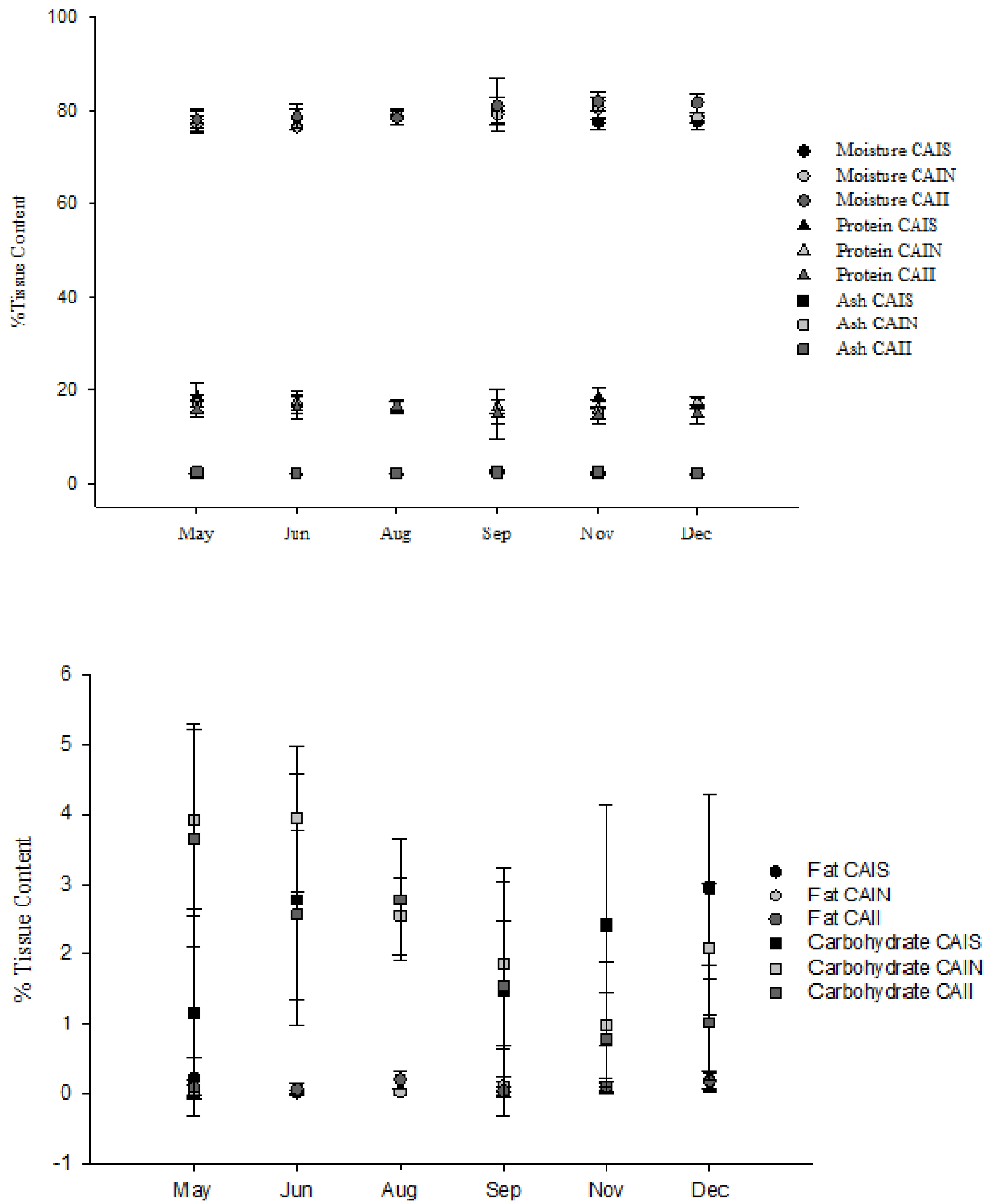


Figure 29. Proximate analysis of > 145 mm SH scallops from southern CAIS (CAIS), northern CAI (CAIN) and CAII in 2012. The mean % fat content is very low in all areas. Values represent the mean (± SD), n = 10.

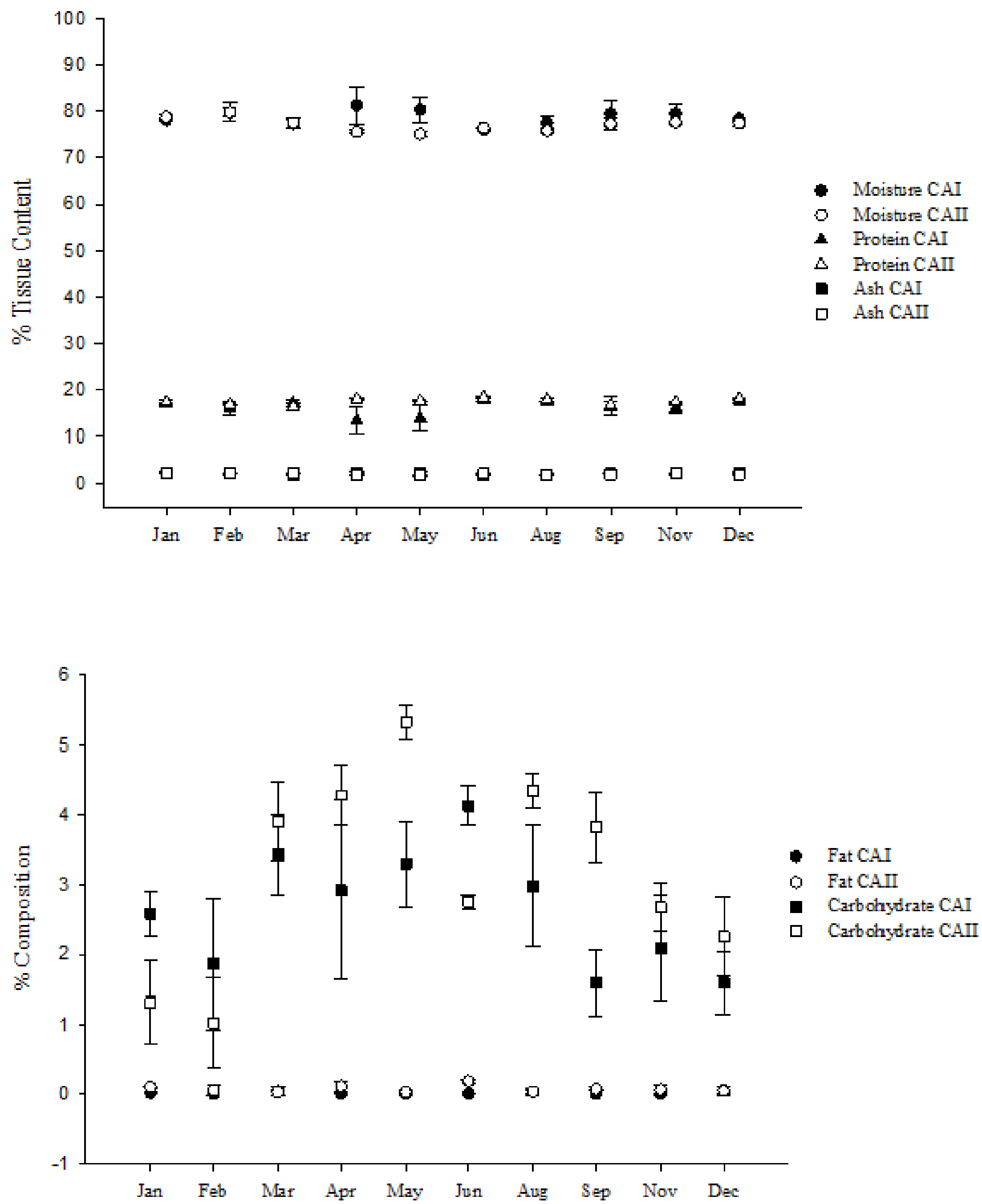


Figure 30. Proximate analysis of ~130 mm SH scallops from CAI and CAII in 2012. The mean % fat content is very low in both areas. Values represent the mean (± SD), n = 10.

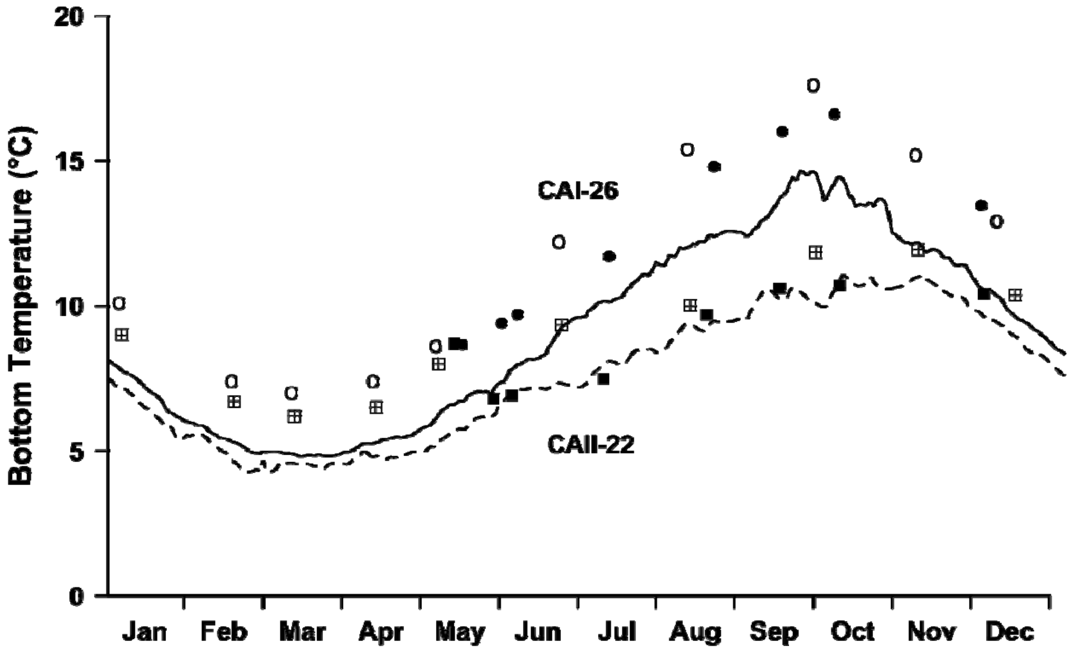


Figure 31. Bottom temperature at CAI-26 (solid line, circles) and CAII-22 (hashed line, squares): FVCOM mean daily estimates from 2000 to 2009 (Chen et al., 2006), measured bottom temperature from May to November 2011 (solid circles) and January to November 2012 (hollow circles).

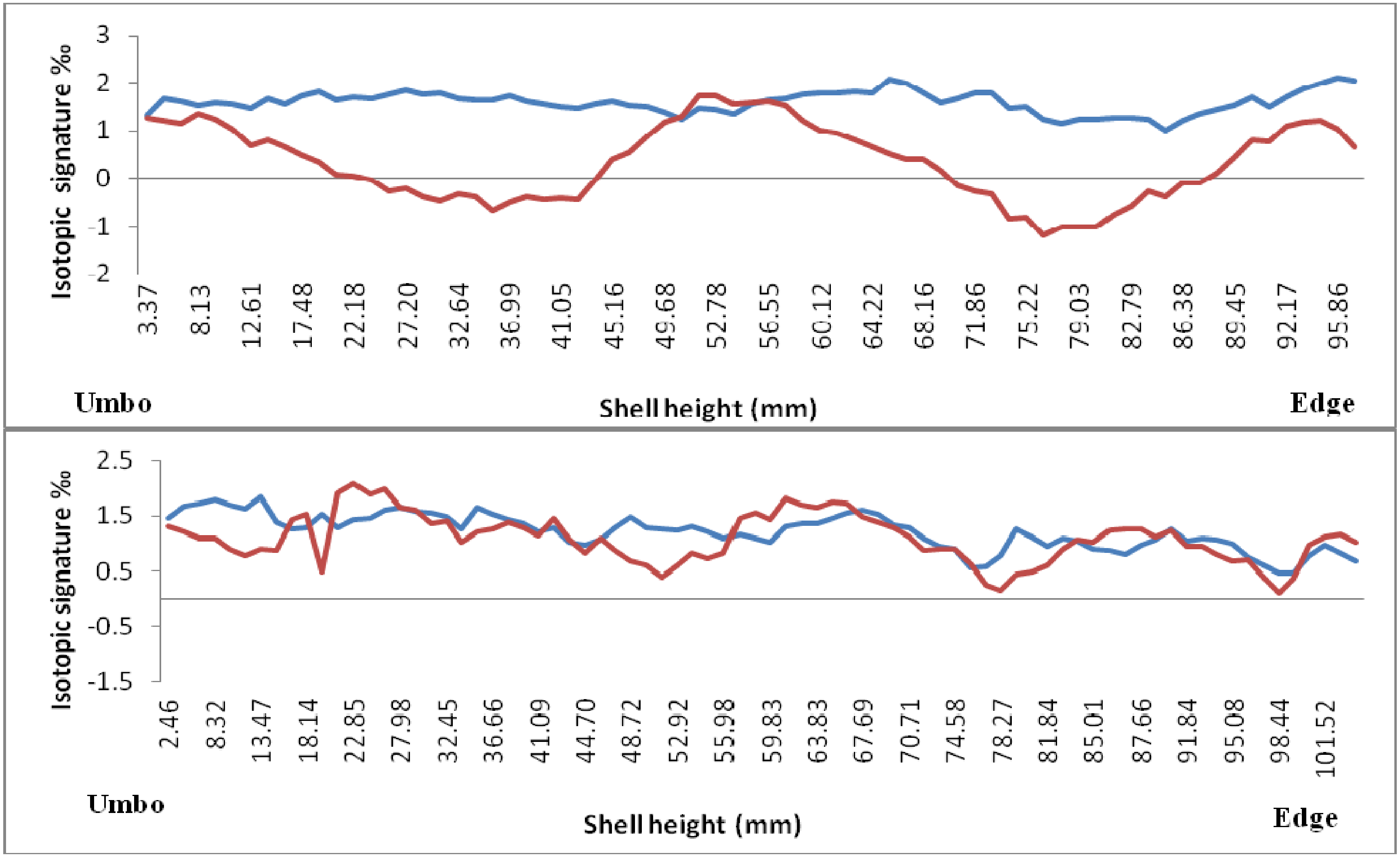


Figure 32. Graphs showing an example of the isotopic signature of scallops from CAI and CAII. CAI is represented in graph A (Station: 26, Date: June 2012 Depth 55-60 meters) and shows well-mixed oceanographic conditions. CAII is represented in graph B (Station: 22 Date: June 2012 ID Depth 75-80 meters) and shows a stratified oceanographic condition. The red line is the ^{18}O isotope signature and the blue line is the ^{13}C isotope signature.

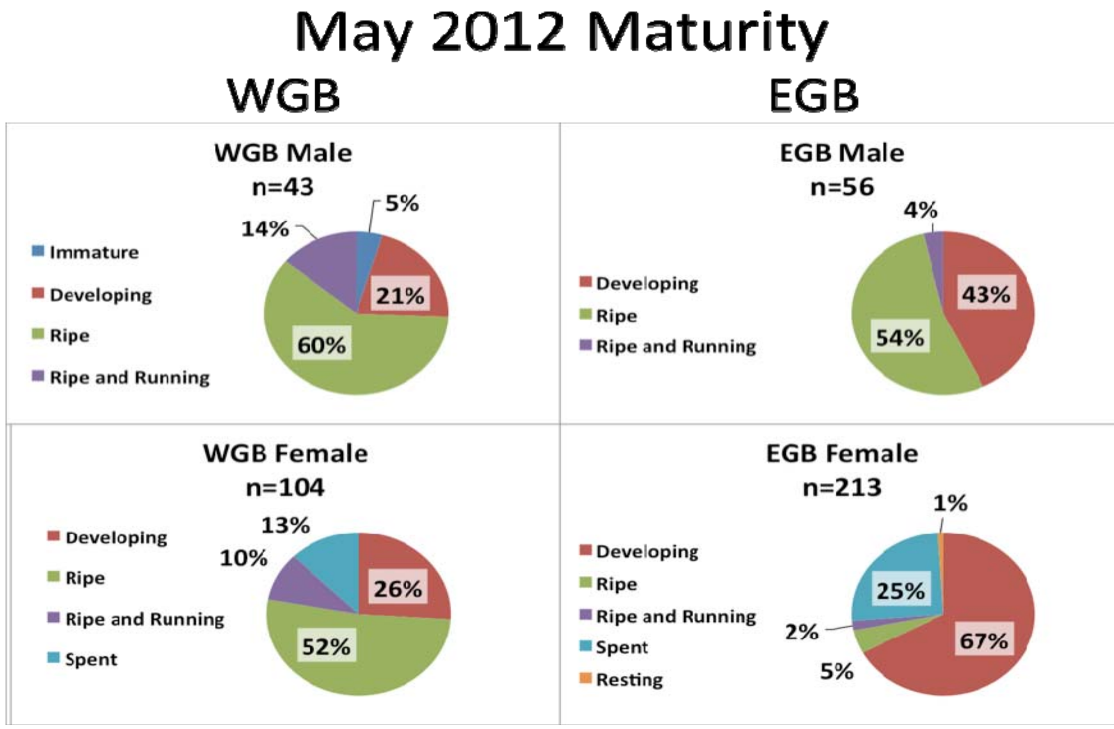


Figure 33. Maturity of yellowtail flounder by area and sex for May 2012.

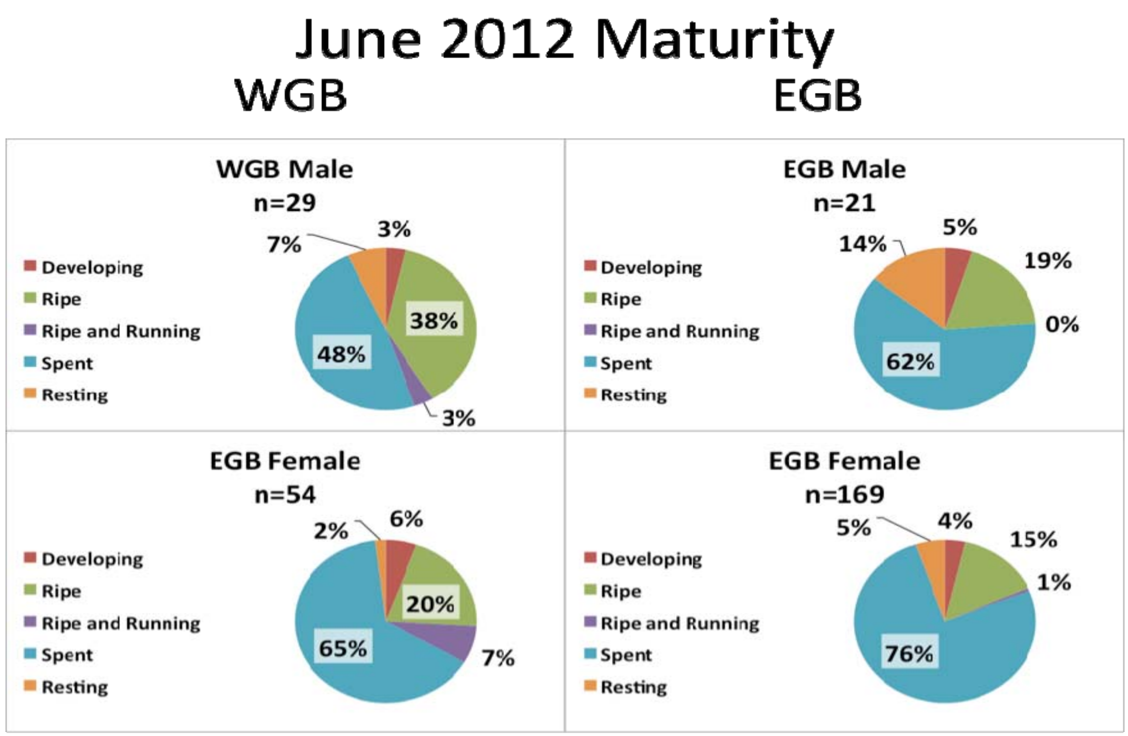


Figure 34. Maturity of yellowtail flounder by area and sex for June 2012.

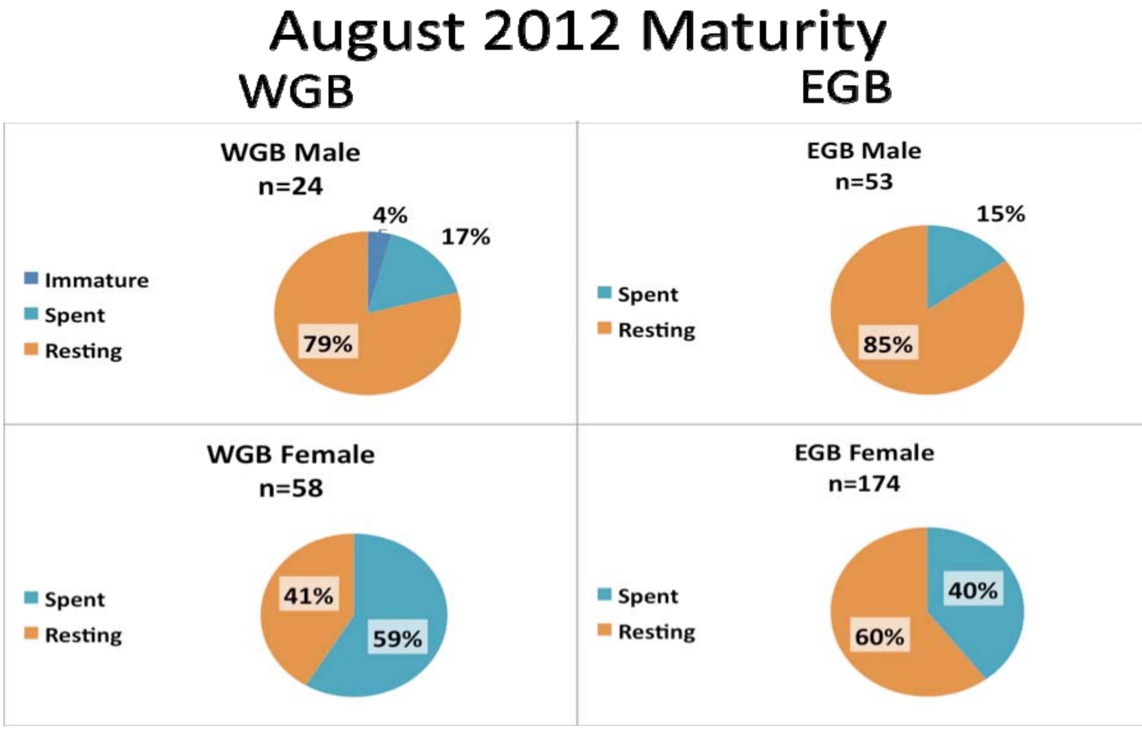


Figure 35. Maturity of yellowtail flounder by area and sex for August 2012.

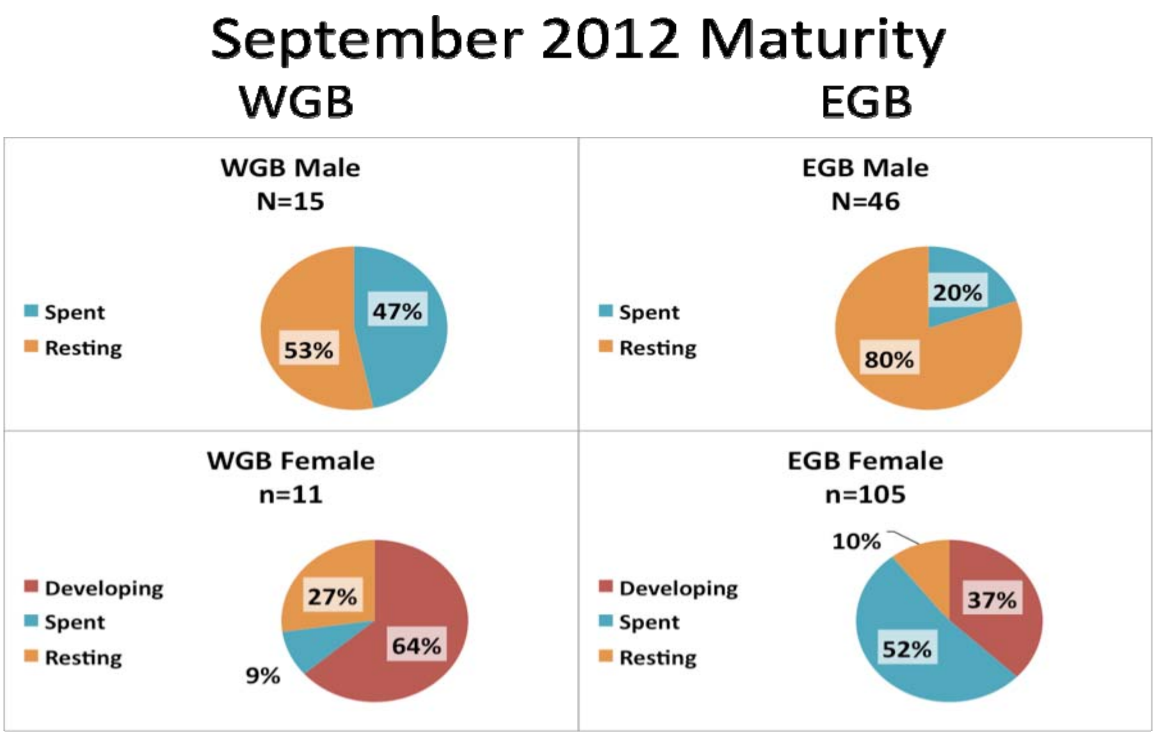


Figure 36. Maturity of yellowtail flounder by area and sex for September 2012.

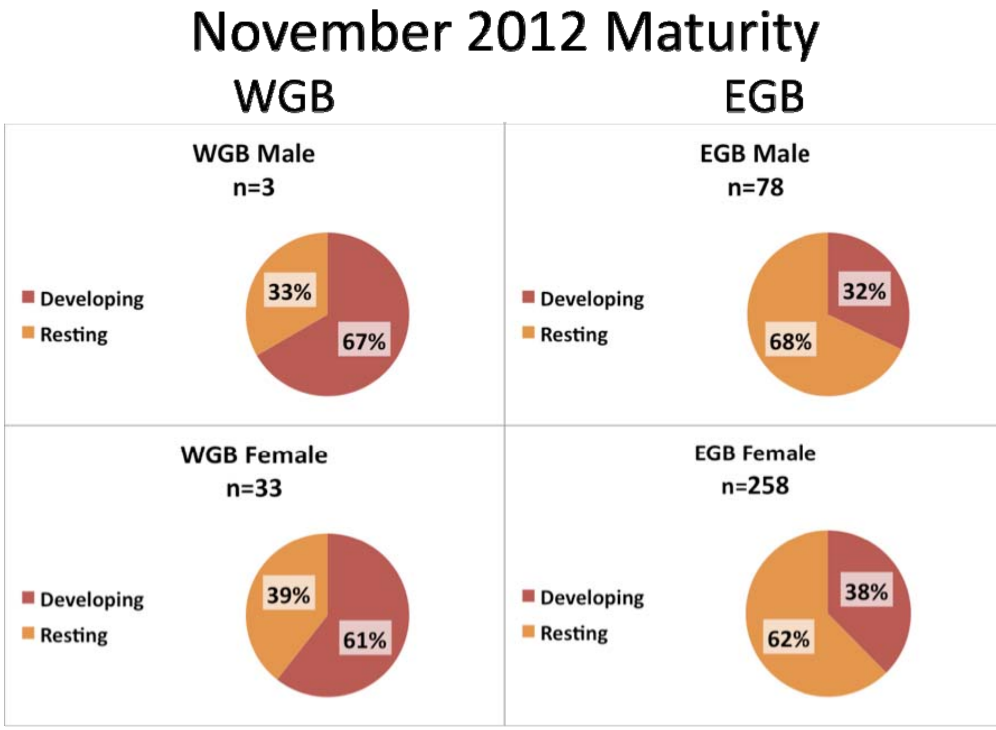


Figure 37. Maturity of yellowtail flounder by area and sex for November 2012.

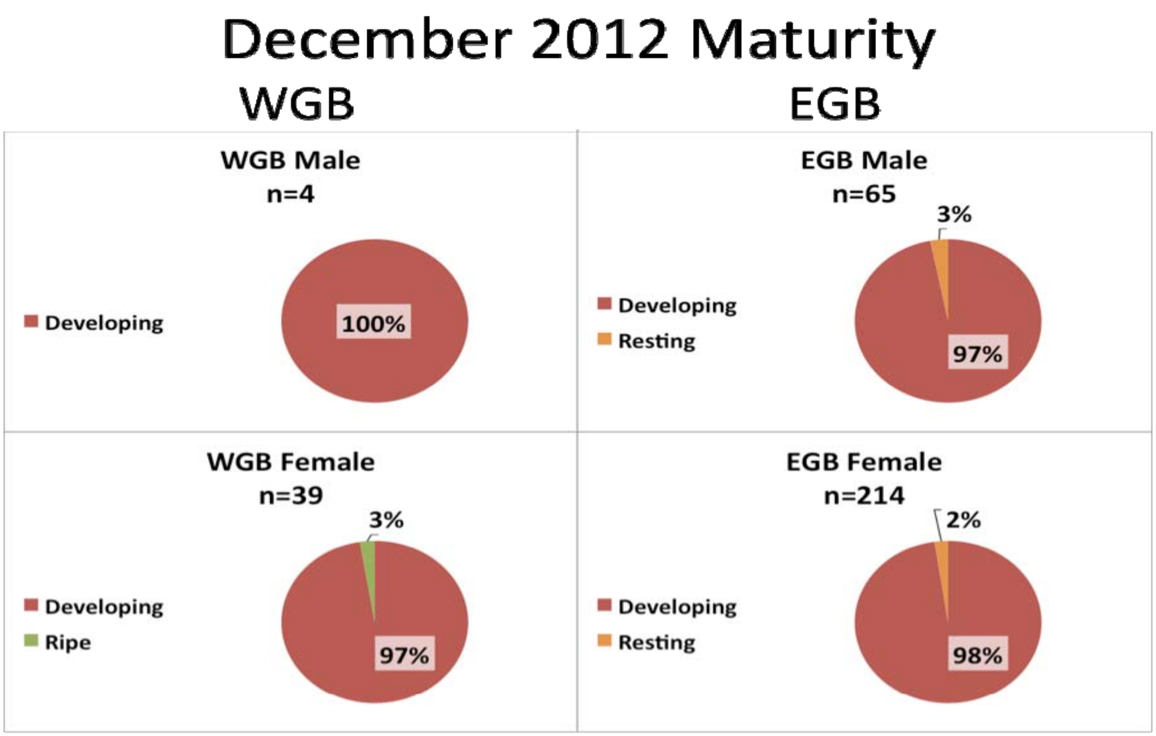


Figure 38. Maturity of yellowtail flounder by area and sex for December 2012.

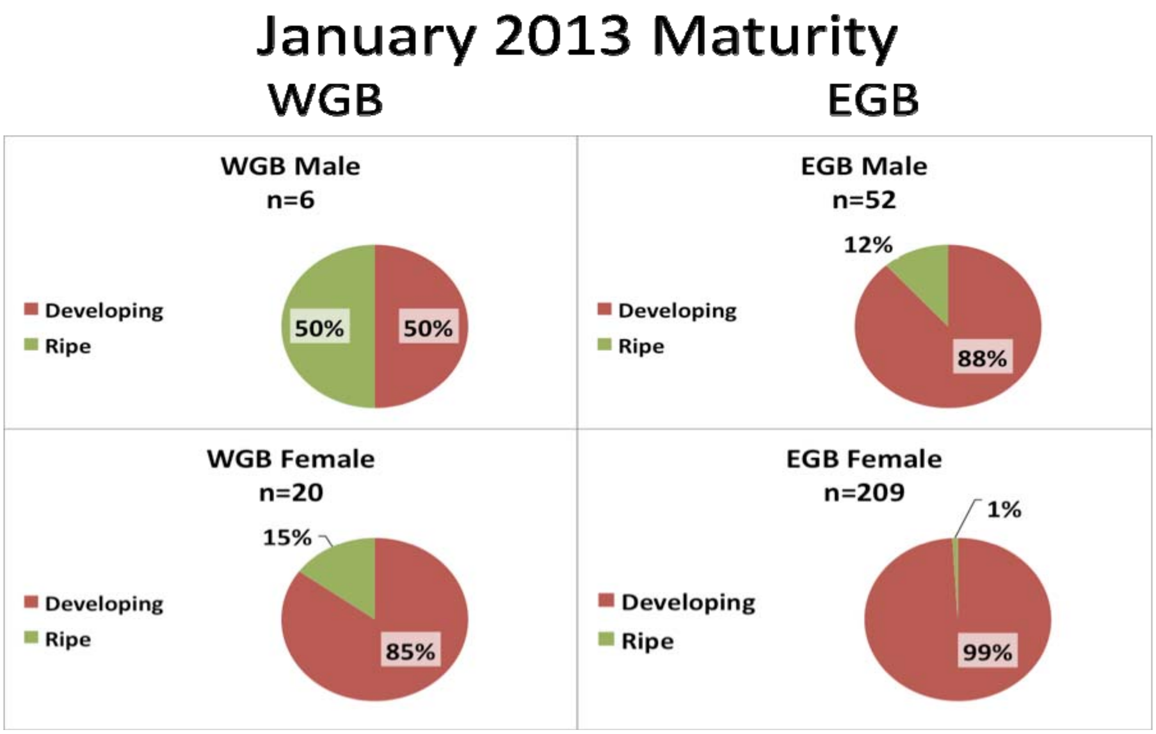


Figure 39. Maturity of yellowtail flounder by area and sex for January 2013.

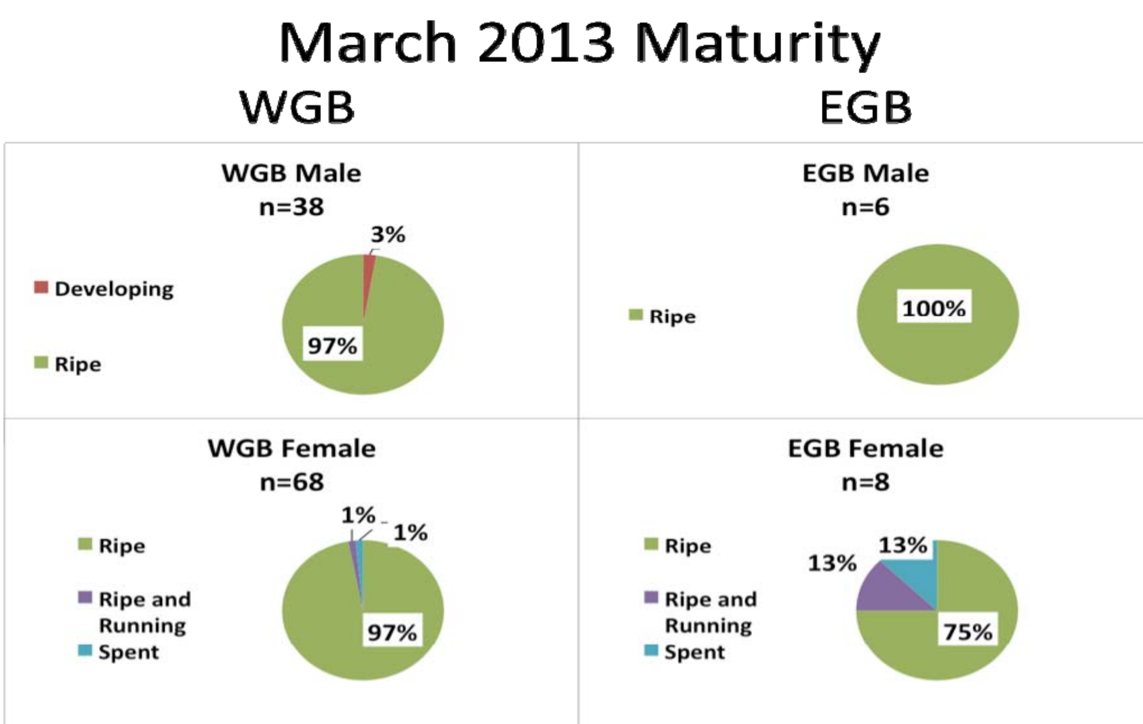


Figure 40. Maturity of yellowtail flounder by area and sex for March 2013.

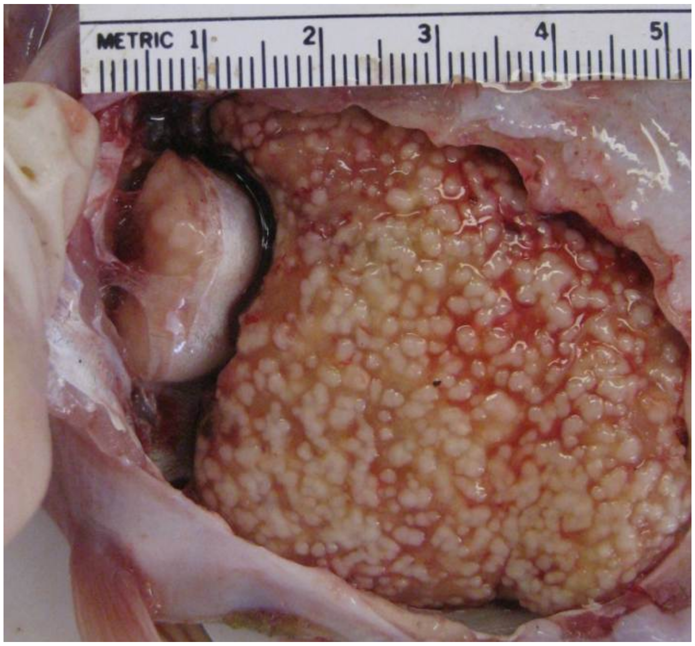


Figure 41. Macroscopic image of a severe *Ichthyophonus* infection, with the characteristic white lesions spreading over the liver and throughout the heart.

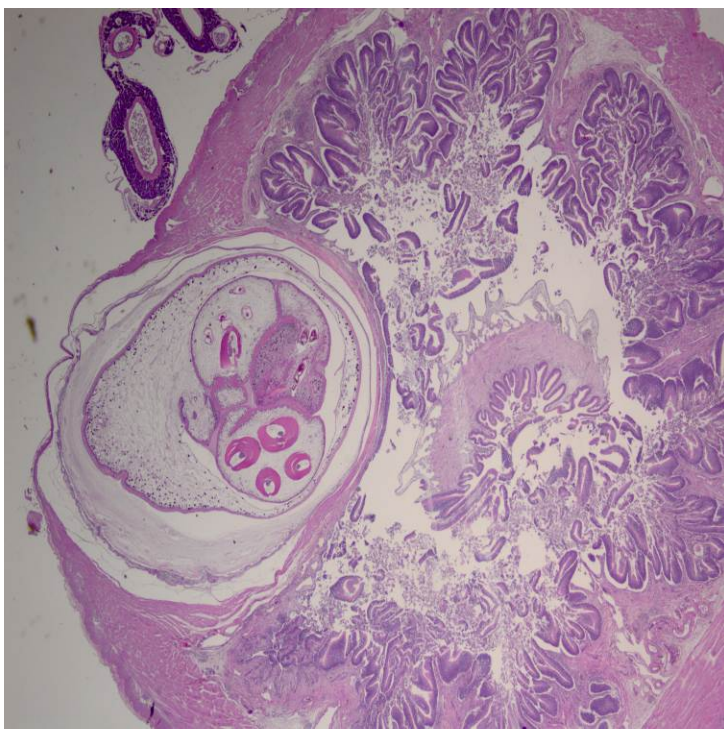


Figure 42. Photomicrograph at 200x magnification of yellowtail flounder stomach tissue showing cestode parasitism (center left).

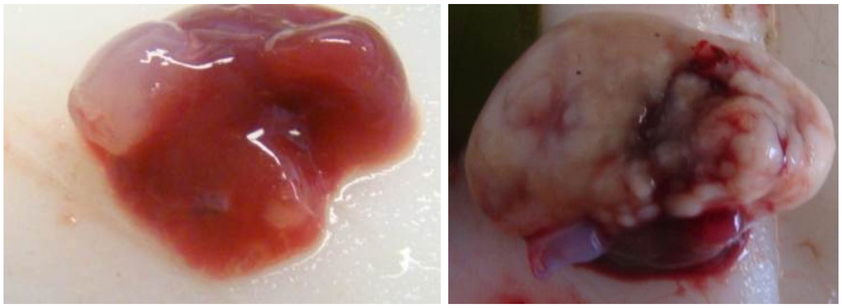


Figure 43. Comparison of a healthy heart (left) and a heart severely infected with *Ichthyophonus* (right).

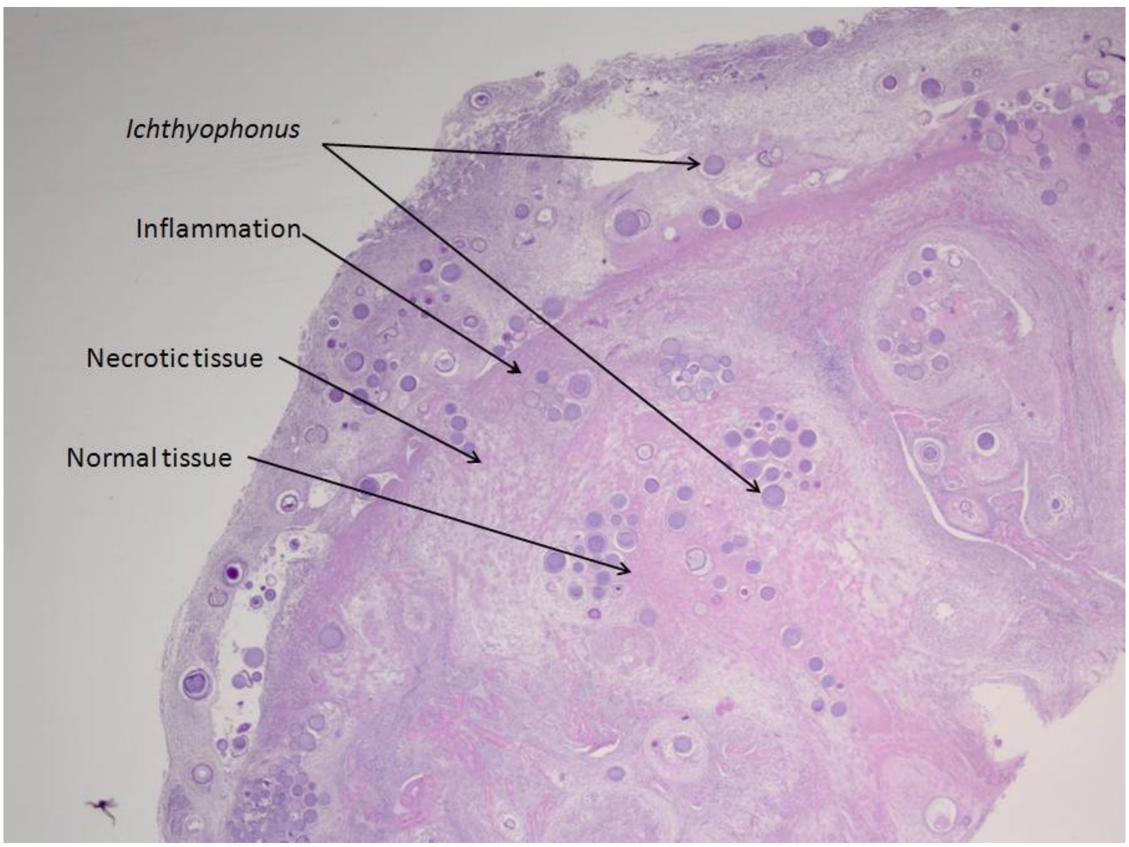


Figure 44. Photomicrograph at 200x magnification of yellowtail flounder heart tissue with severe myocardial *Ichthyophonus* infection and resulting cellular necrosis.

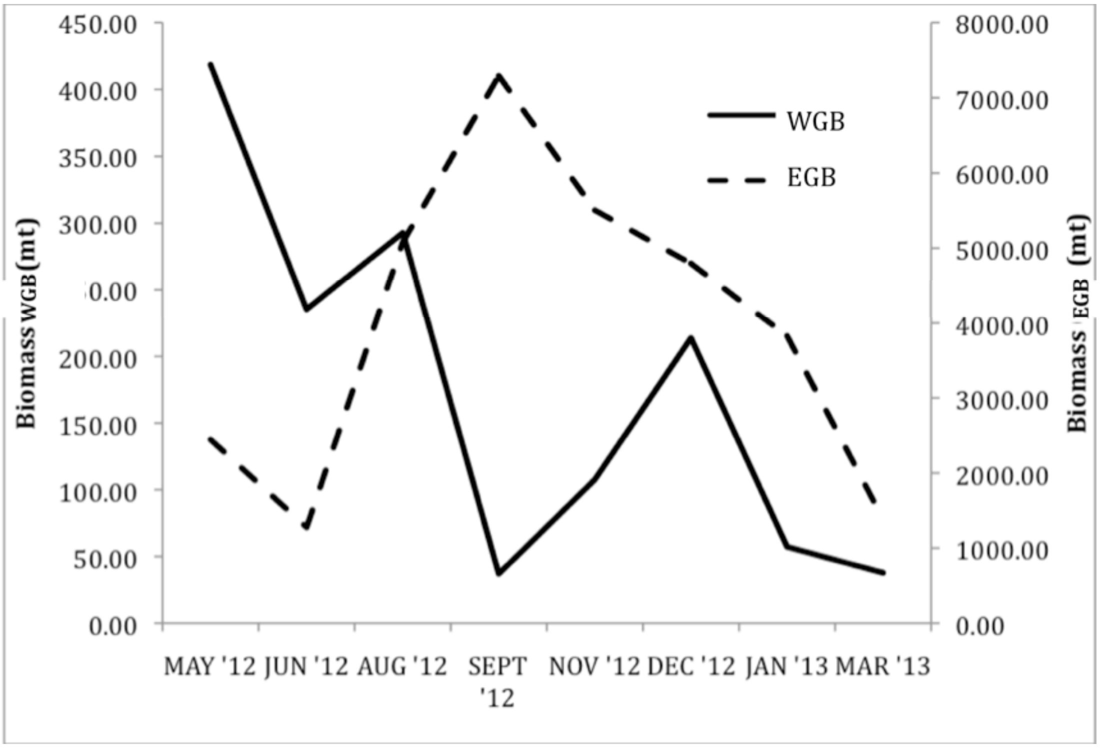


Figure 45. Yellowtail flounder biomass estimates for Western Georges Bank (WGB) and Eastern Georges Bank (EGB). WGB biomass on the primary y-axis and EGB biomass values are on the secondary y-axis.

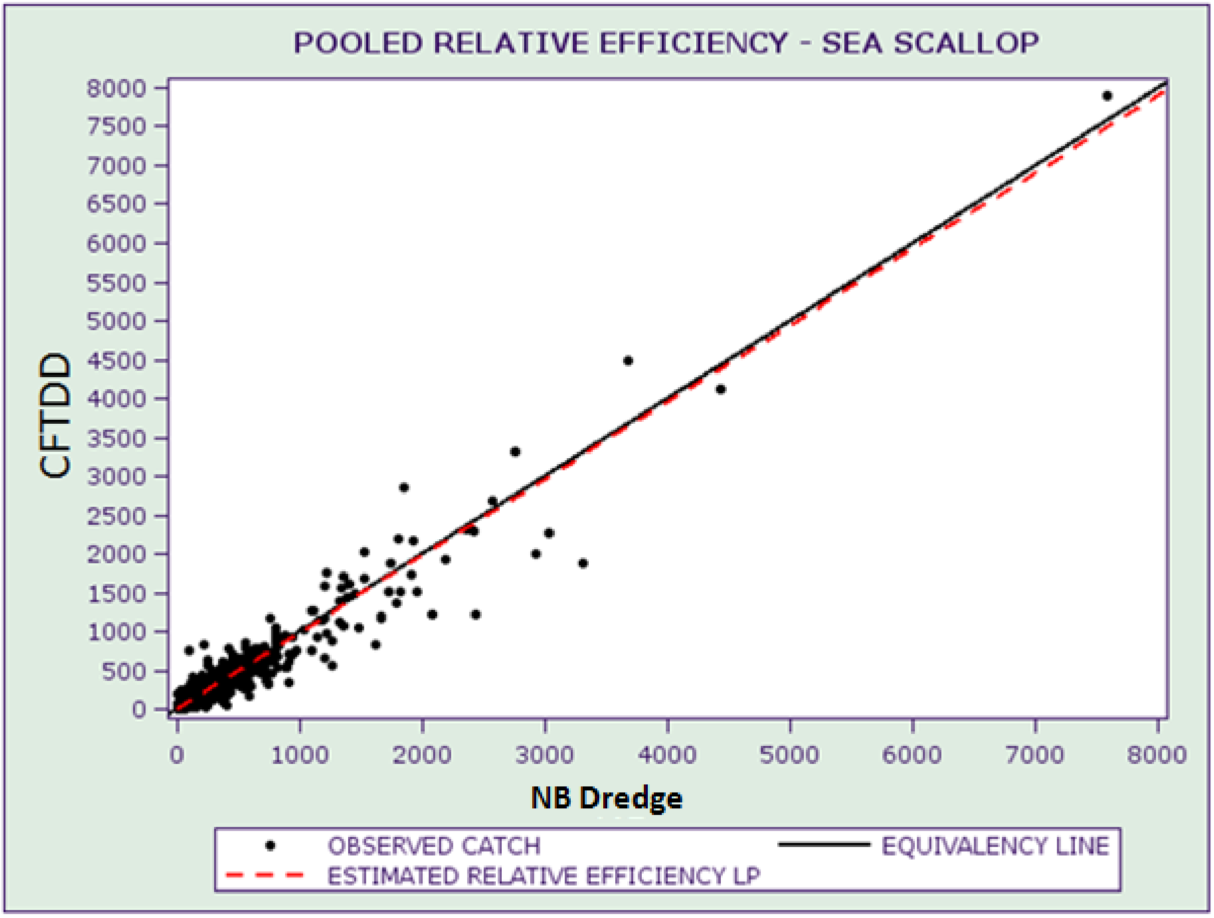


Figure 46. Total pooled catches for Sea Scallop for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was not the most appropriate specification. However it is informative to see that the total catch of this species did not differ between dredges while a significant length relationship exists.

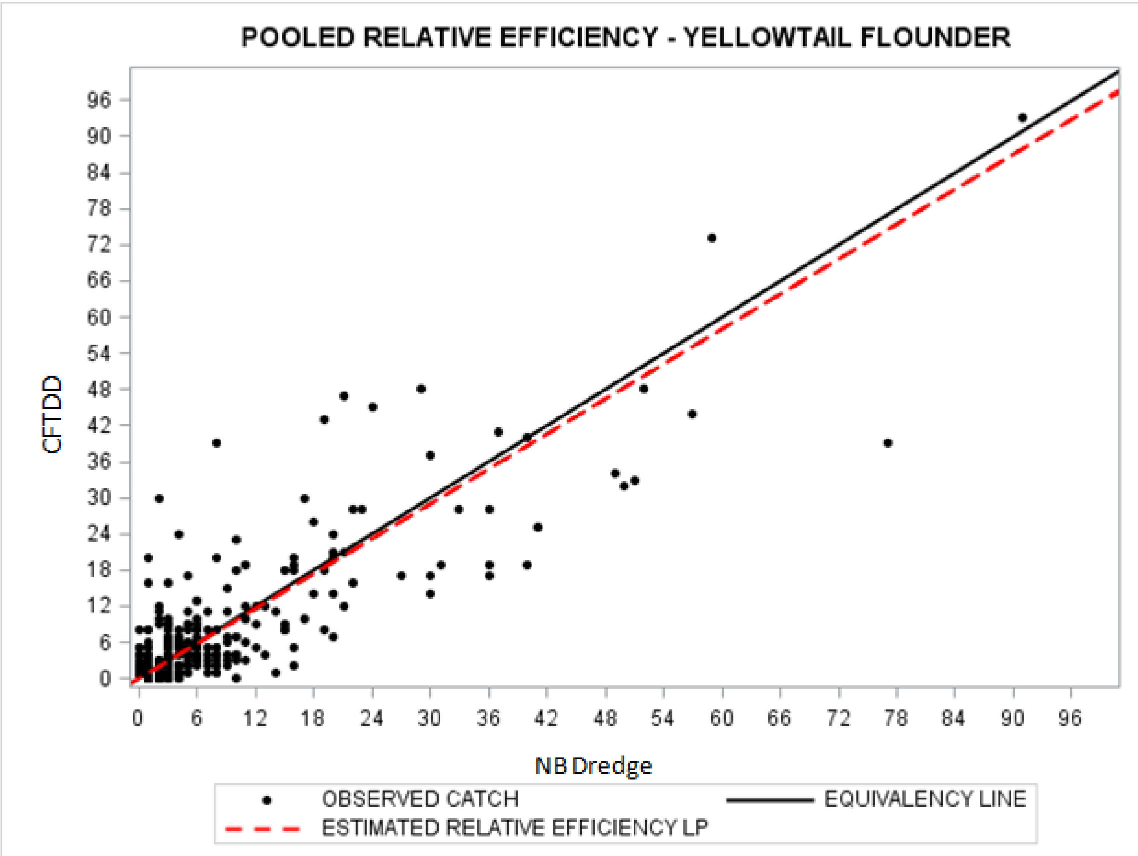


Figure 47. Total pooled catches for Yellowtail Flounder for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

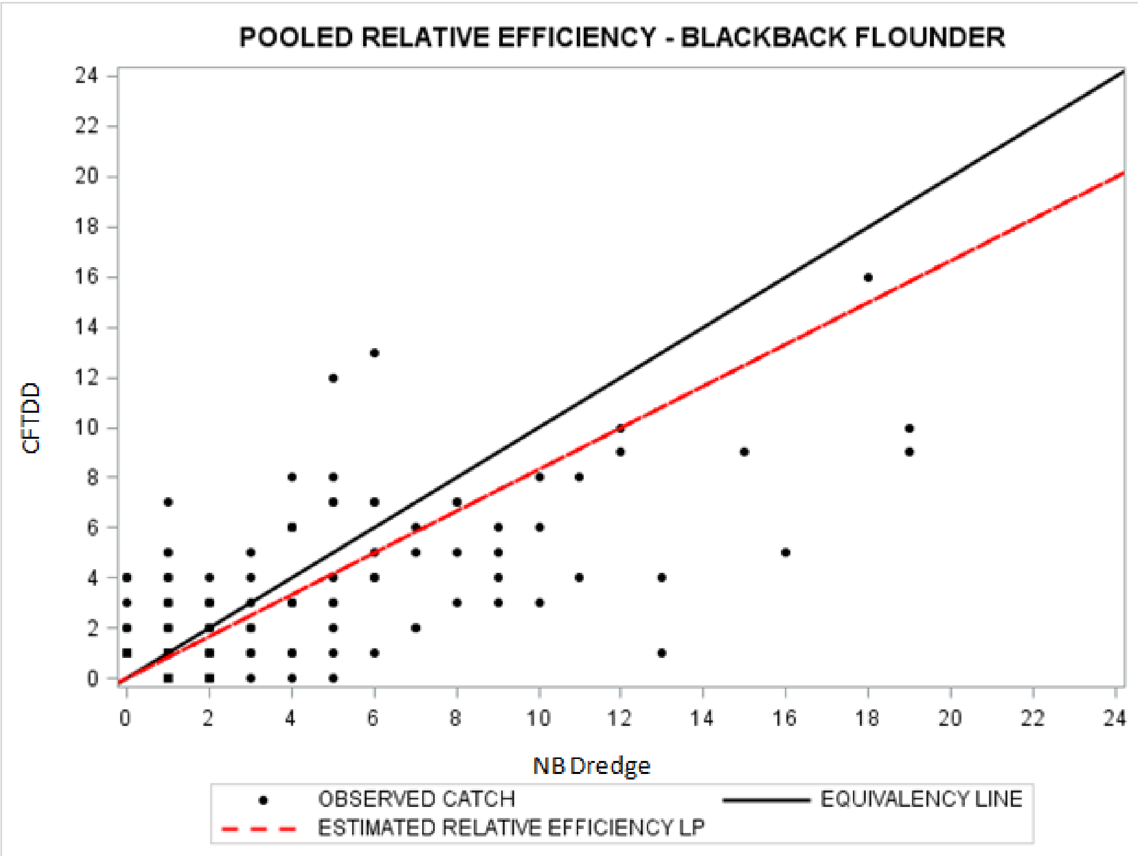


Figure 48. Total pooled catches for Yellowtail Flounder for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

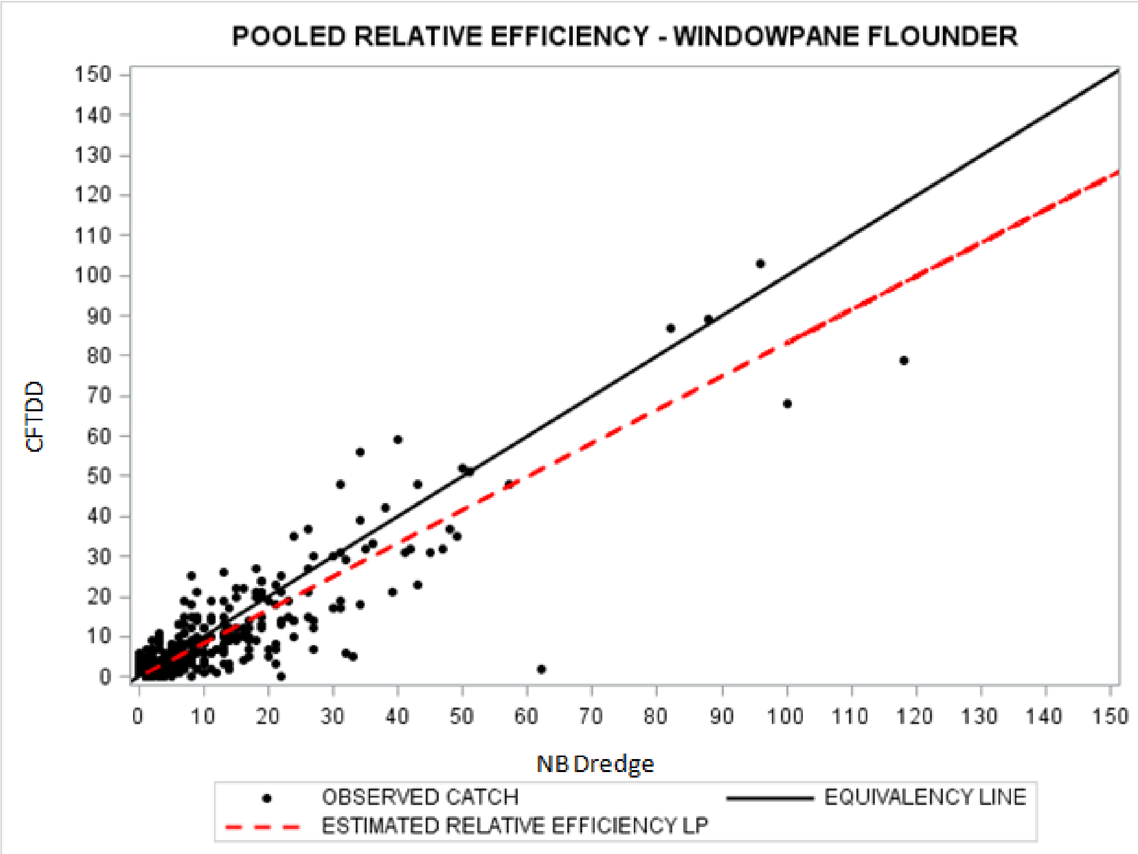


Figure 49. Total pooled catches for Windowpane Flounder for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

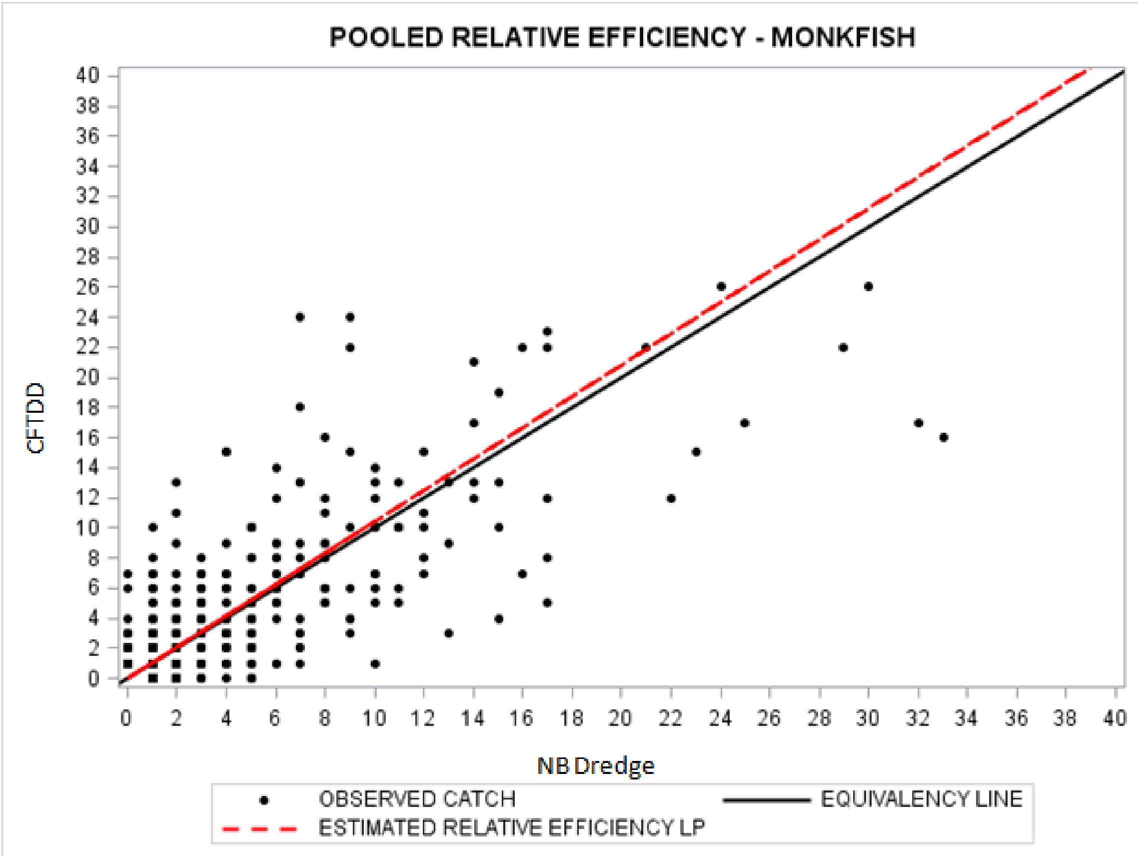


Figure 50. Total pooled catches for Monkfish for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

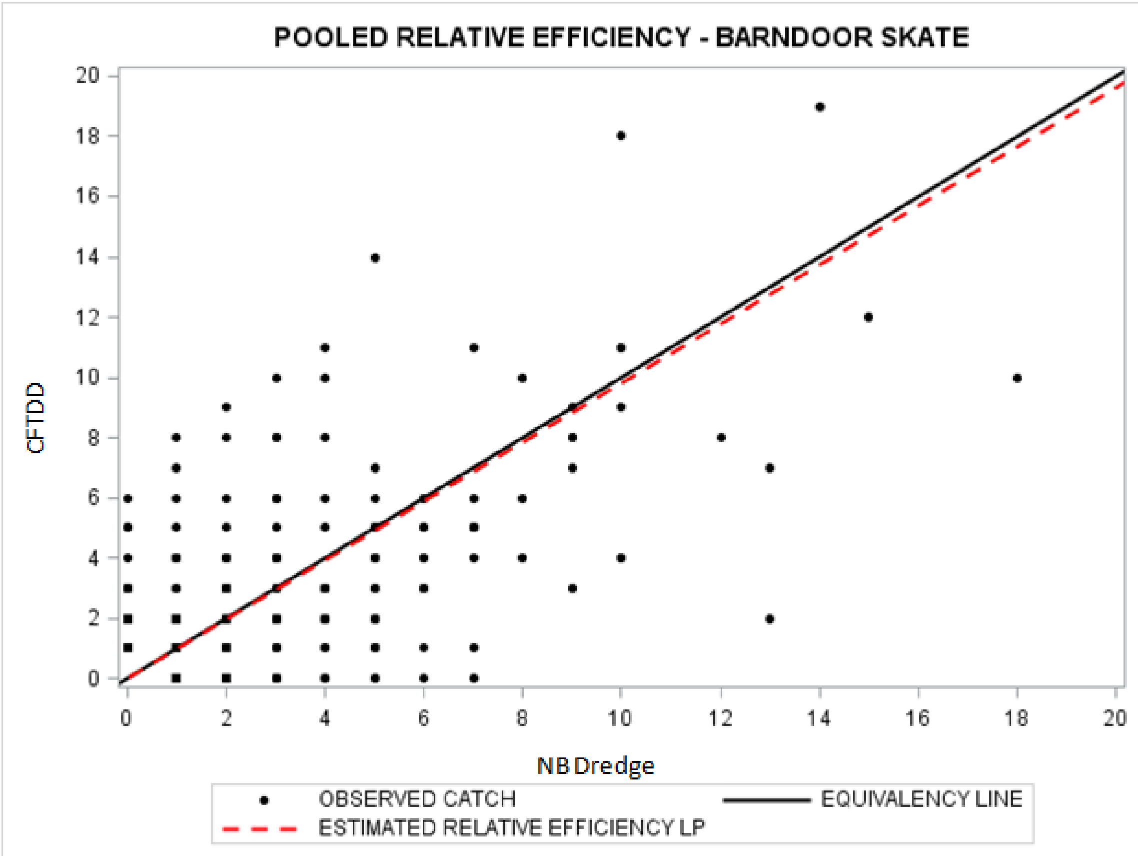


Figure 51. Total pooled catches for Barndoor Skate for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was not the most appropriate specification. However it is informative to see that the total catch of this species did not differ between dredges while a significant length relationship exists. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

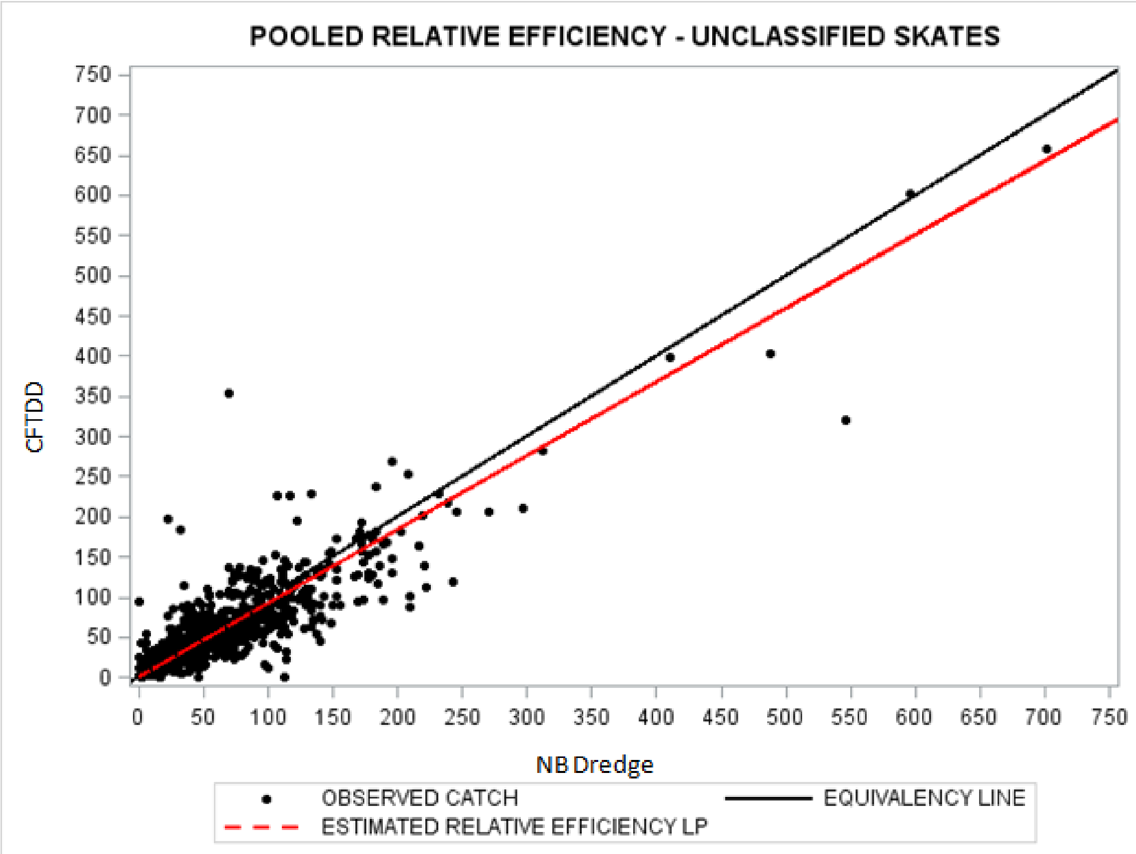


Figure 52. Total pooled catches for Unclassified Skates for the CFTDD vs. the NB dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

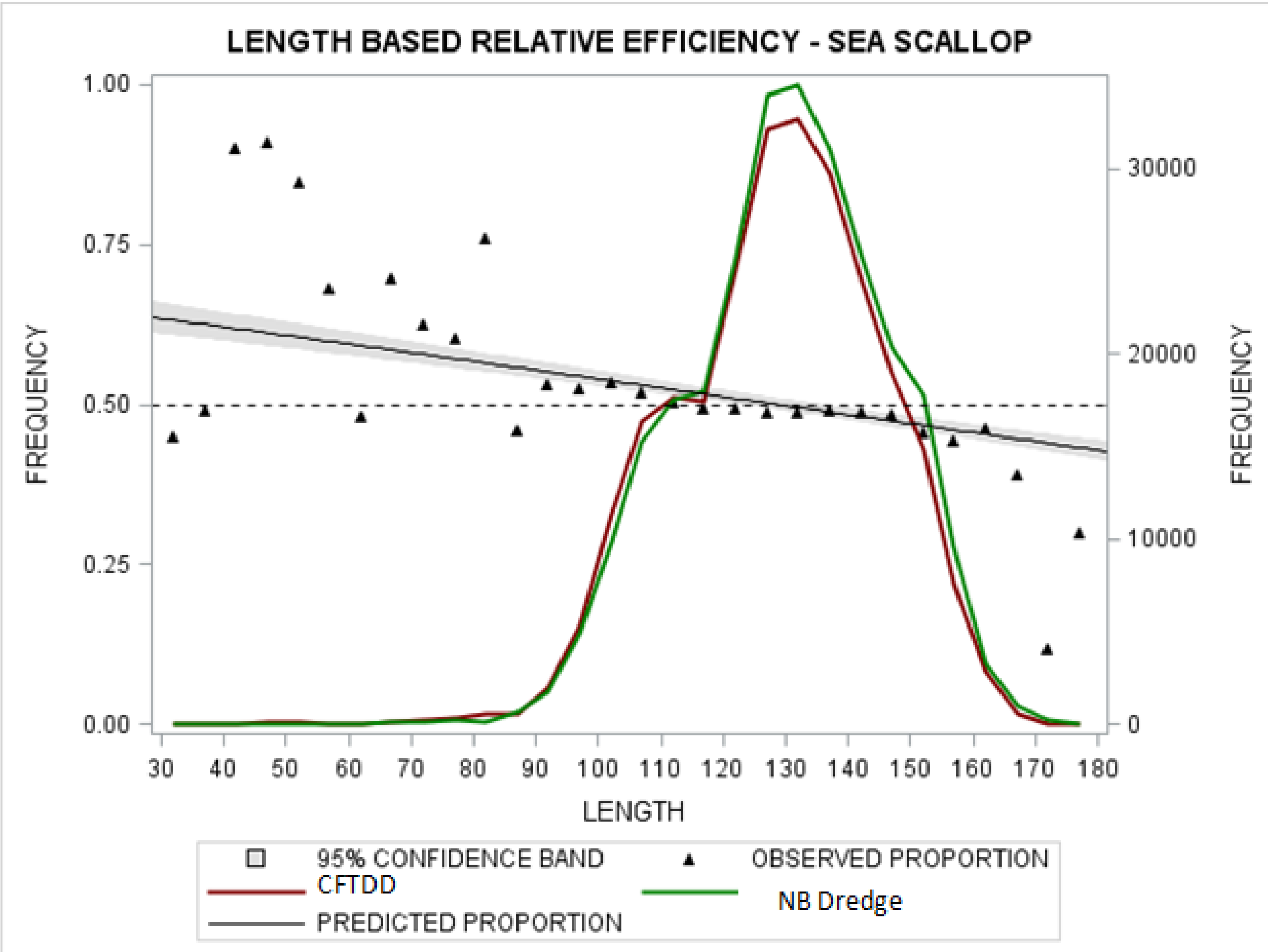


Figure 53. Relative Sea Scallop catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{CFTDD}/(Catch_{CFTDD} + Catch_{NB})$), with a proportion >0.5 representing more animals at length captured by the CFTDD. The grey area represents the 95% confidence band for the modeled proportion (solid black line).

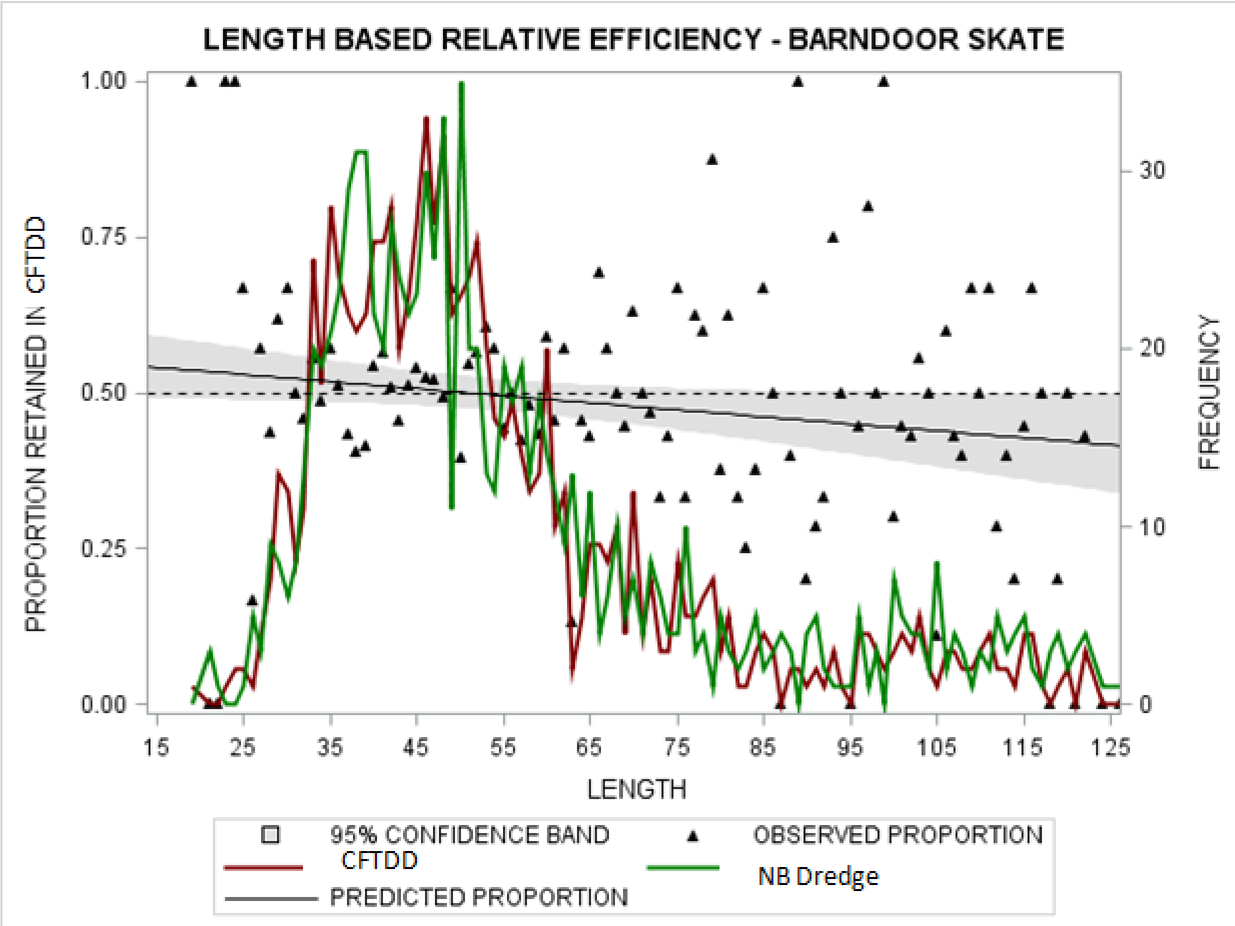
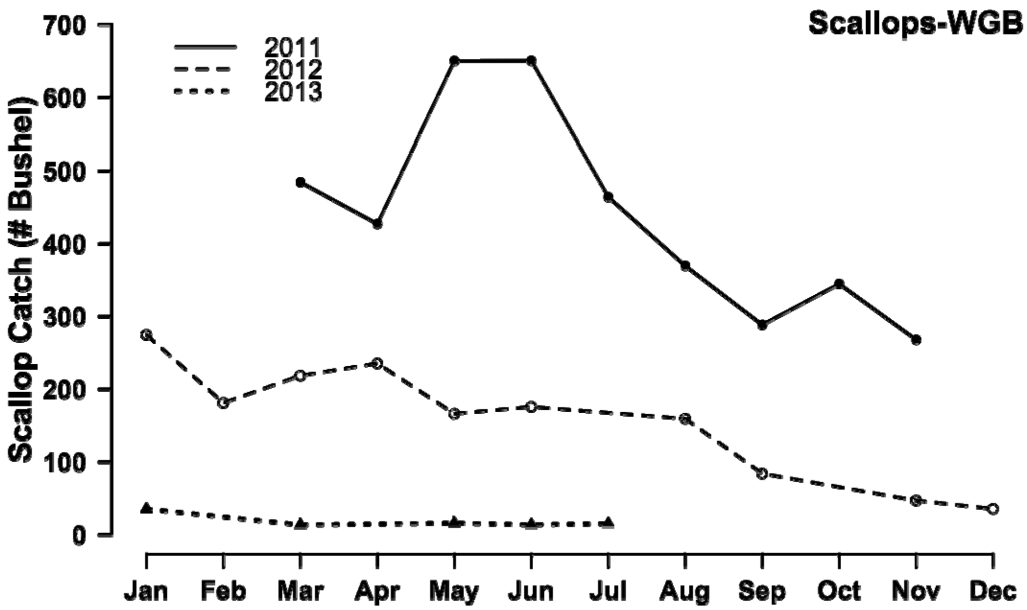
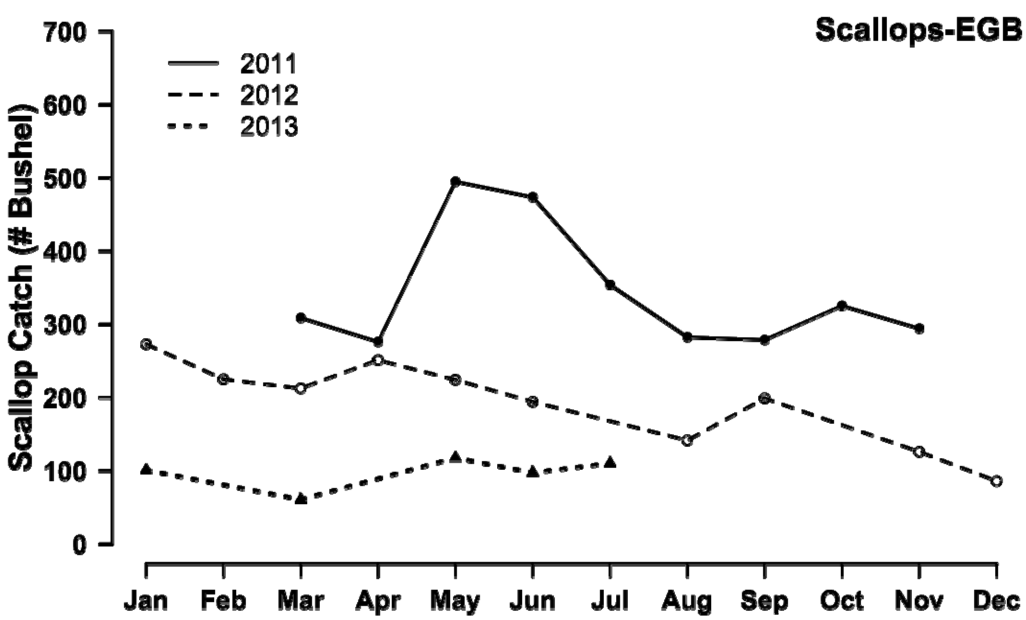


Figure 54. Relative Barndoor Skate catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{CFTDD}/(Catch_{CFTDD} + Catch_{NB})$, with a proportion >0.5 representing more animals at length captured by the CFTDD. The grey area represents the 95% confidence band for the modeled proportion (solid black line).

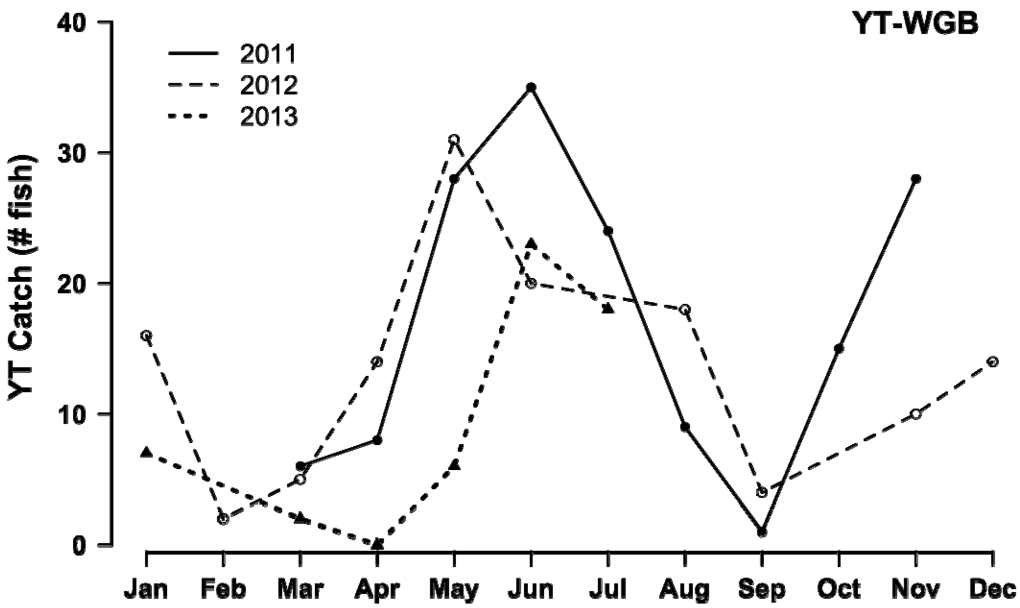
Appendix A



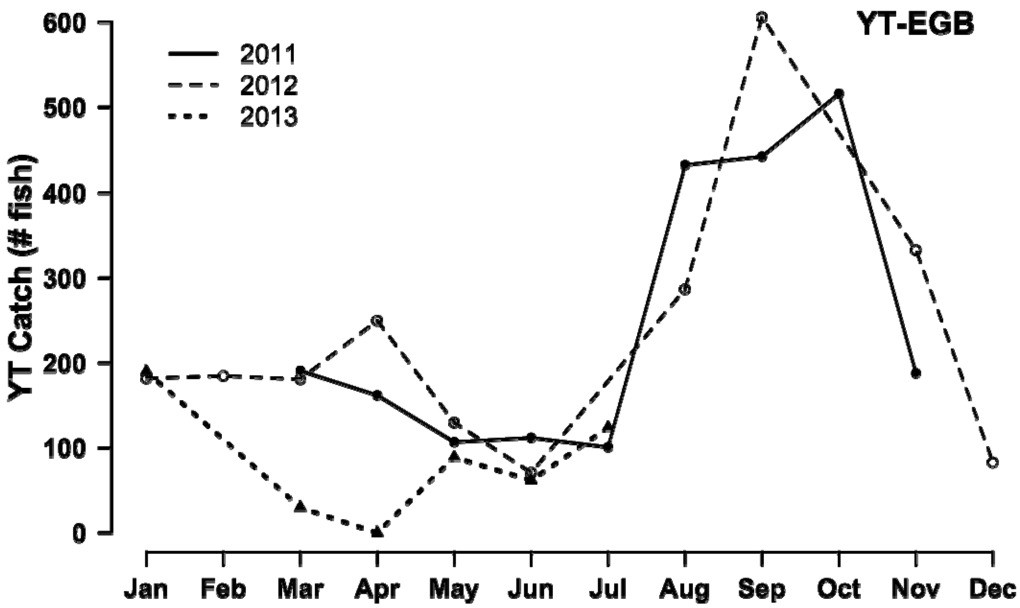
Appendix A Figure 1. Scallop catch (# bushels) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



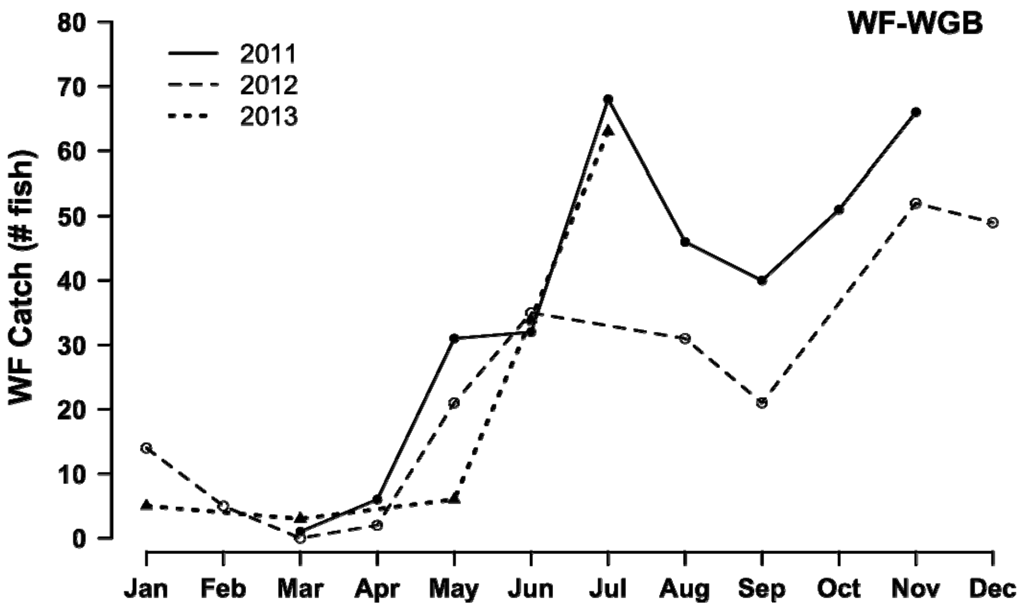
Appendix A Figure 2. Scallop catch (# bushels) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).



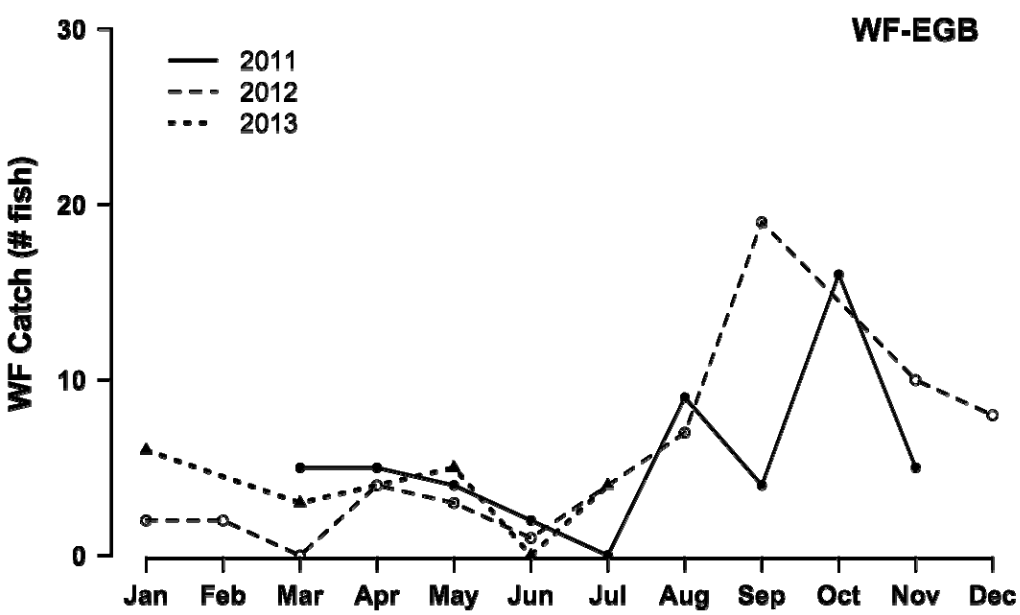
Appendix A Figure 3. Yellowtail catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



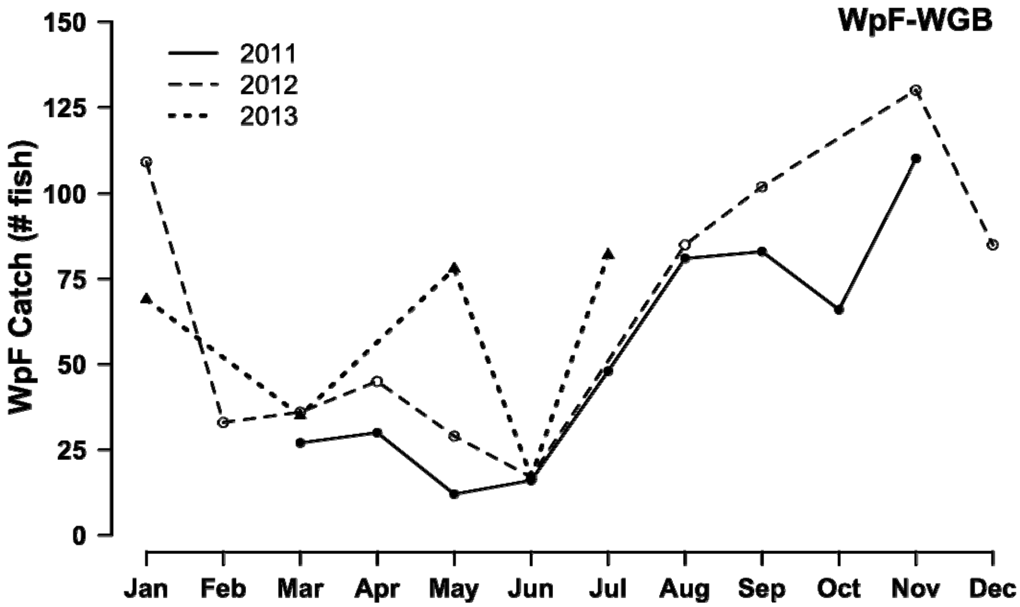
Appendix A Figure 4. Yellowtail catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).



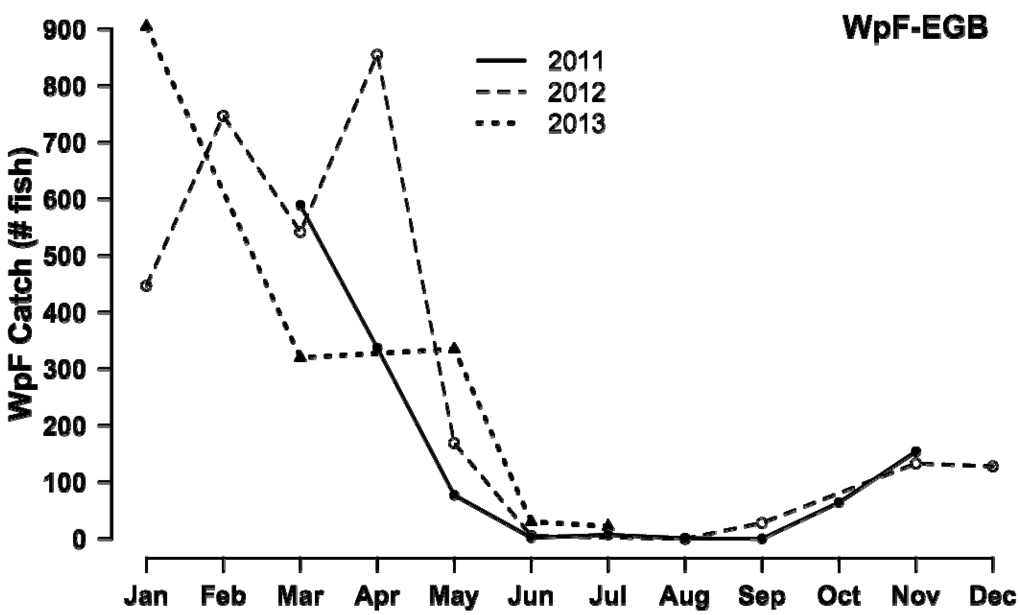
Appendix A Figure 5. Winter flounder catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



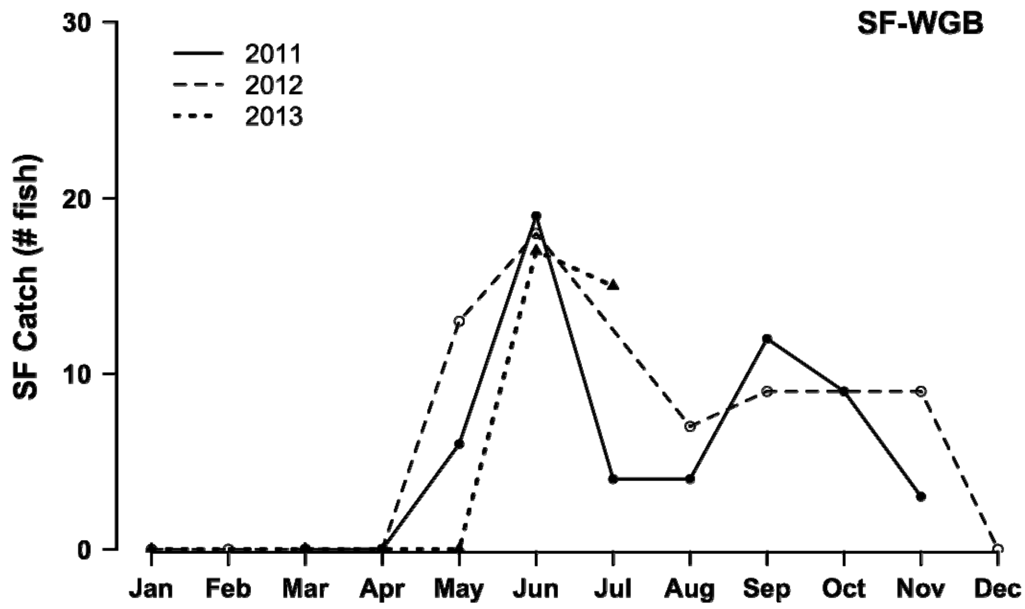
Appendix A Figure 6. Winter flounder catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).



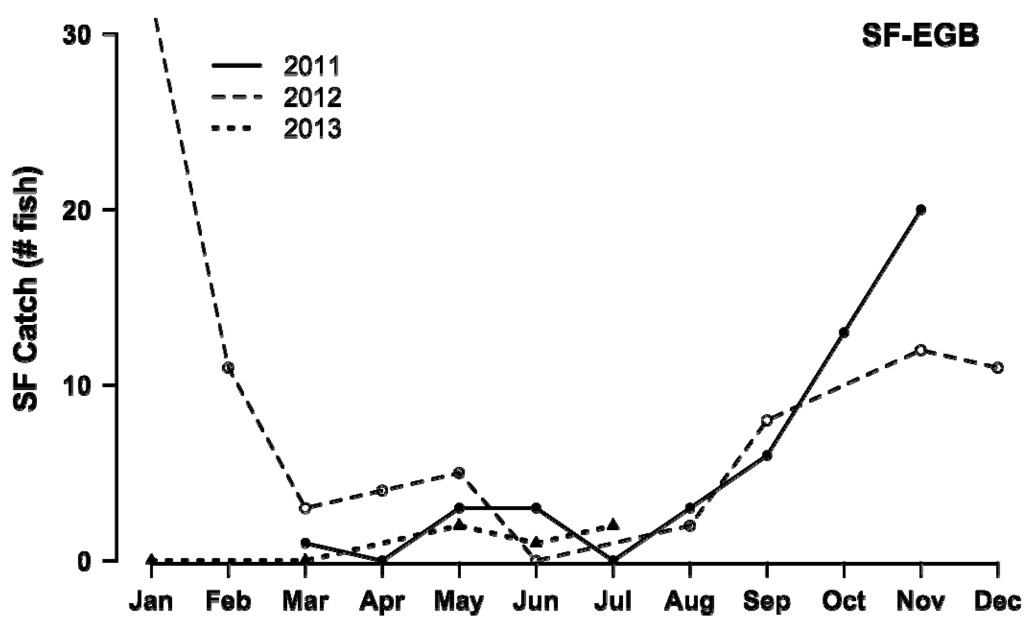
Appendix A Figure 7. Windowpane flounder catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



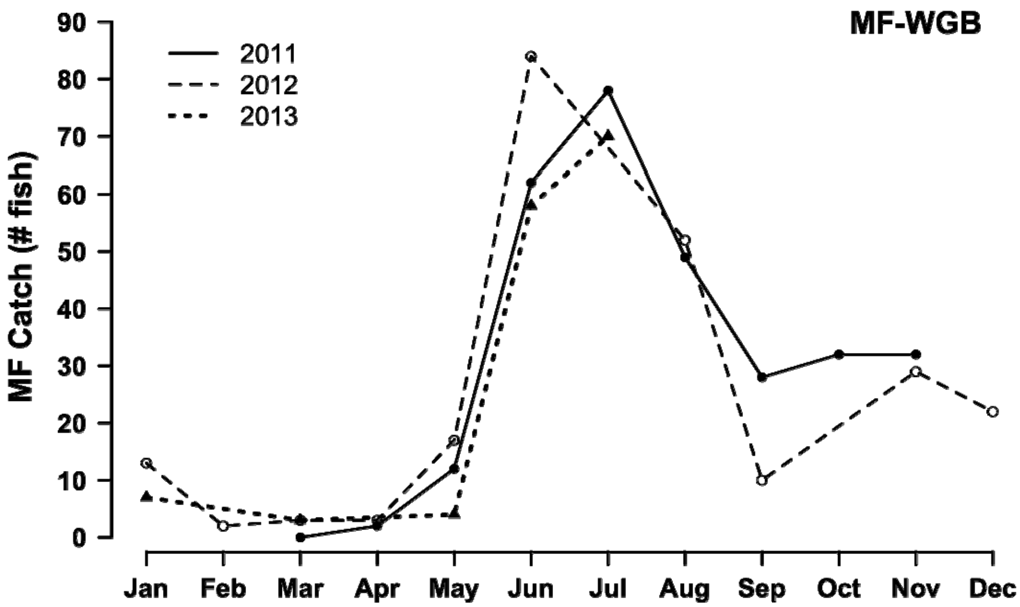
Appendix A Figure 8. Windowpane flounder catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).



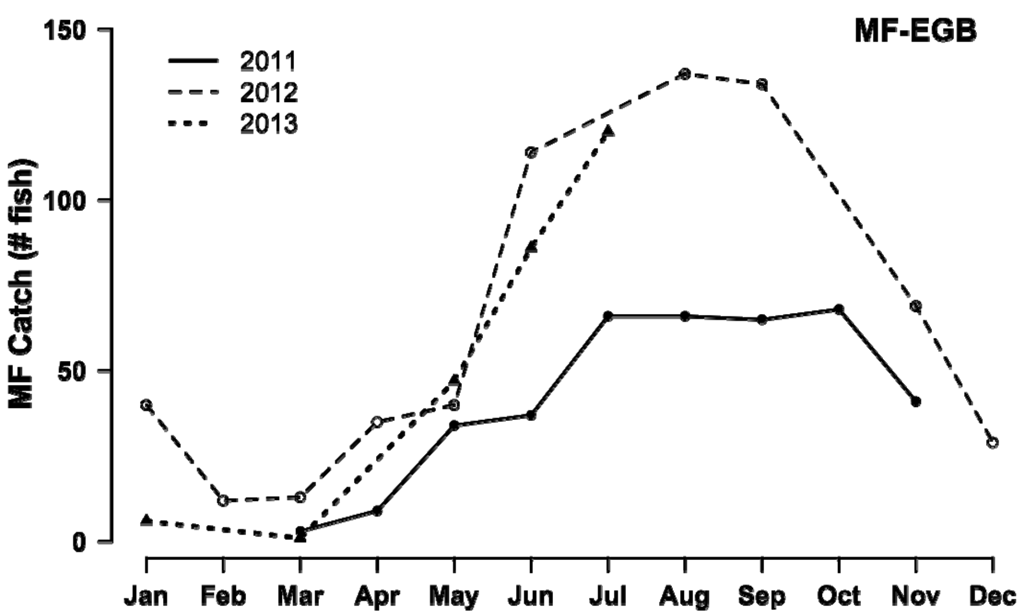
Appendix A Figure 9. Summer flounder catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



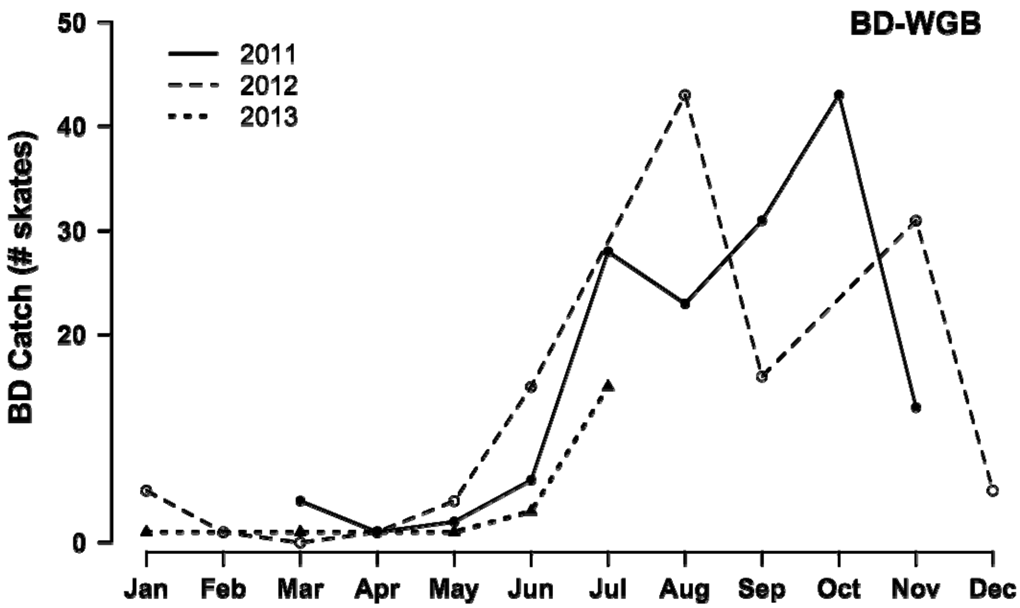
Appendix A Figure 10. Summer flounder catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).



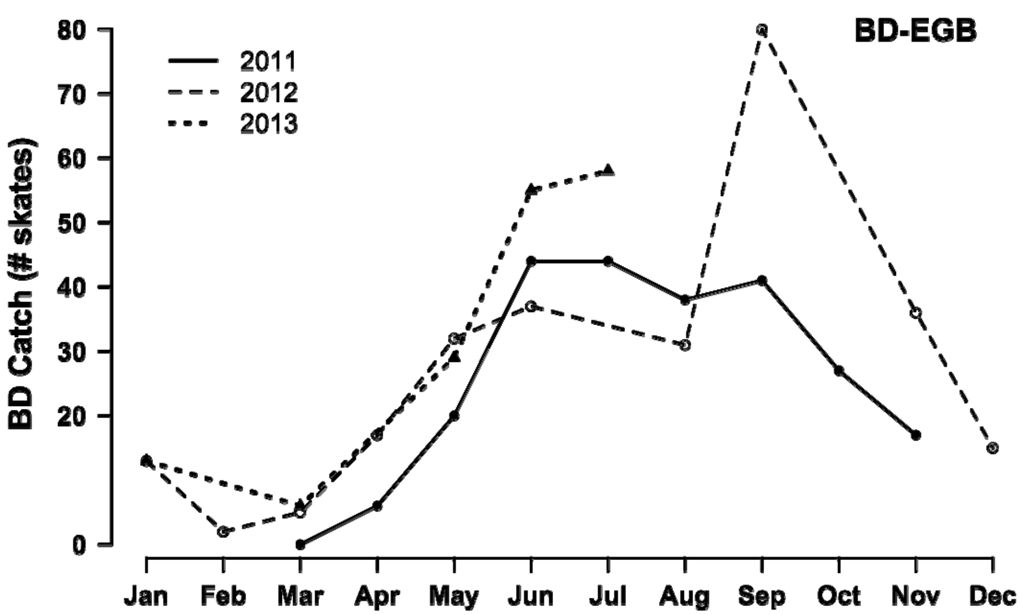
Appendix A Figure 11. Monkfish catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



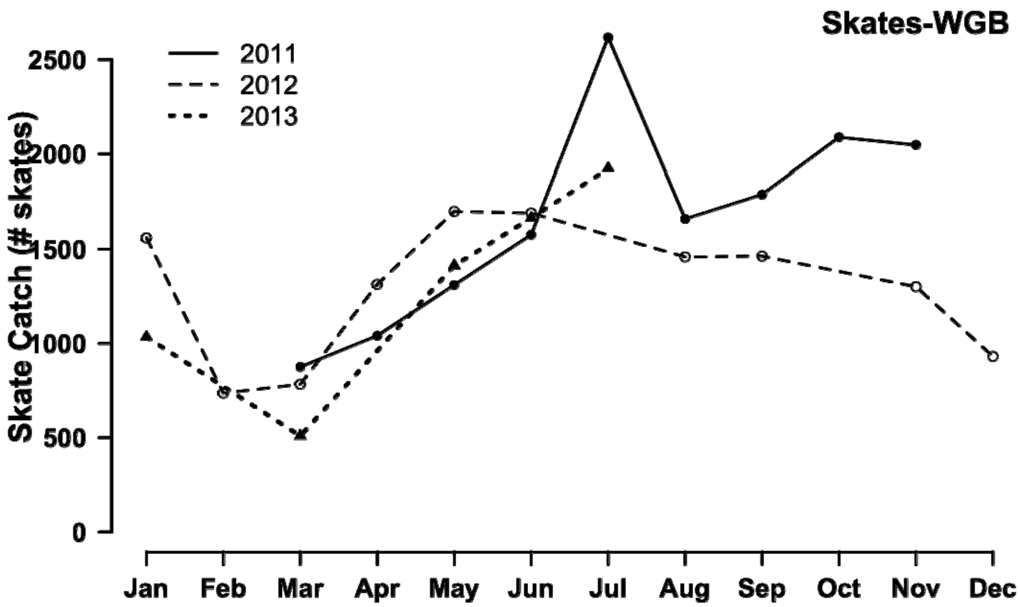
Appendix A Figure 12. Monkfish catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).



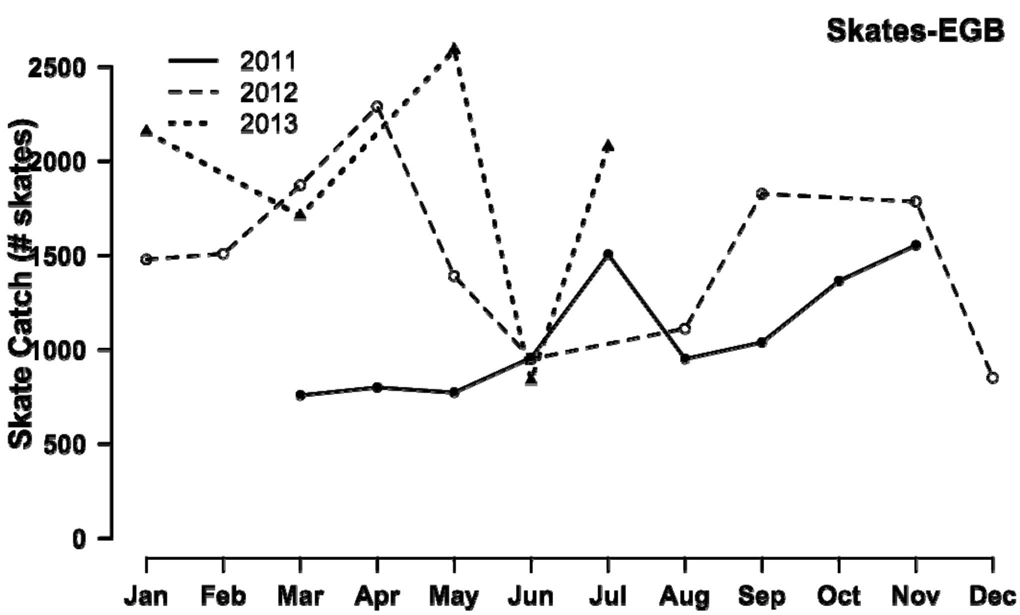
Appendix A Figure 13. Barndoor skate catch (# skates) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).



Appendix A Figure 14. Barndoor skate catch (# fish) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).

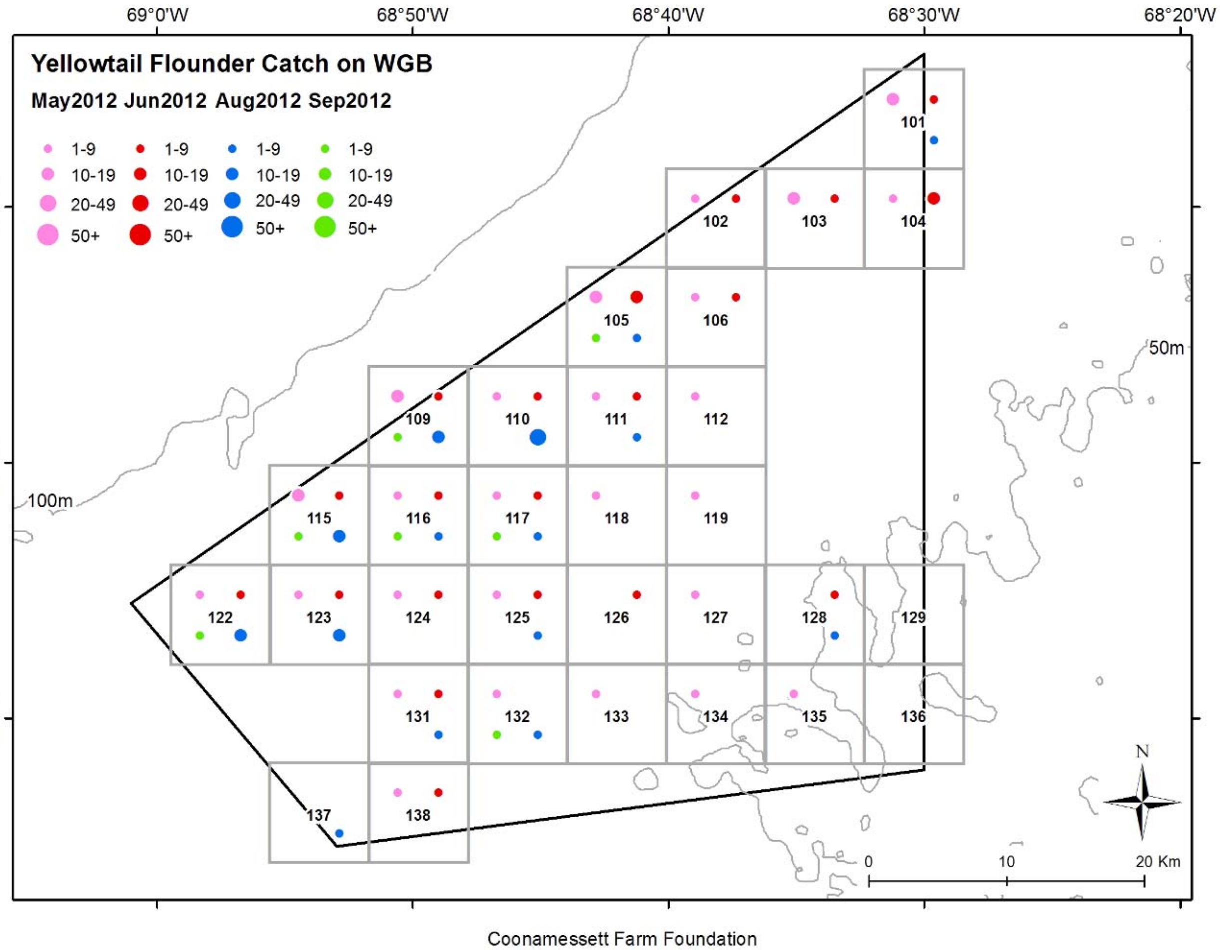


Appendix A Figure 15. Unclassified skate catch (# skates) in the standardized CFTDD from March 2011 through July 2013 at 14 stations consistently sampled on Western Georges Bank (CAI).

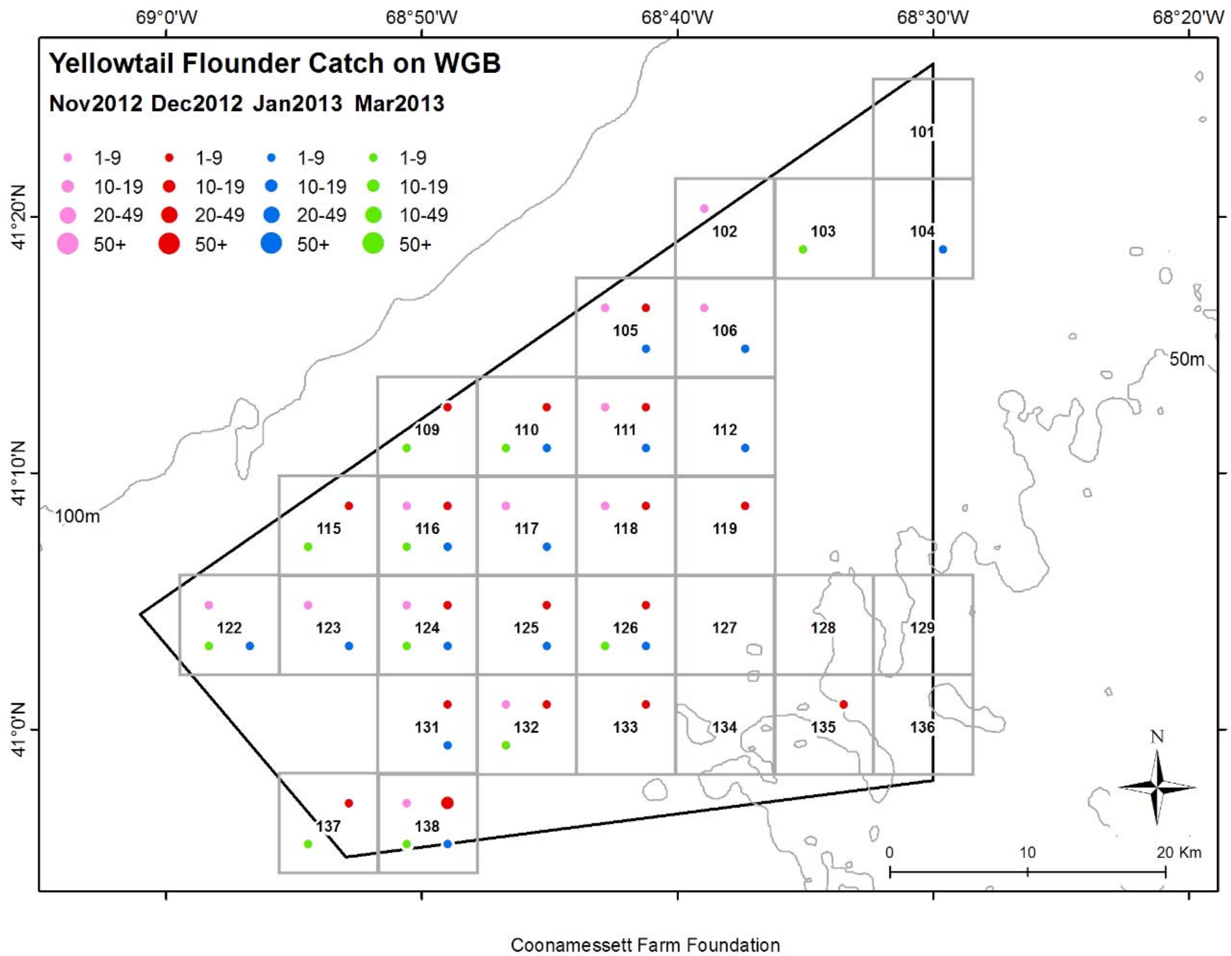


Appendix A Figure 16. Unclassified skate catch (# skates) in the standardized CFTDD from March 2011 through July 2013 at 28 stations consistently sampled on Eastern Georges Bank (CAII).

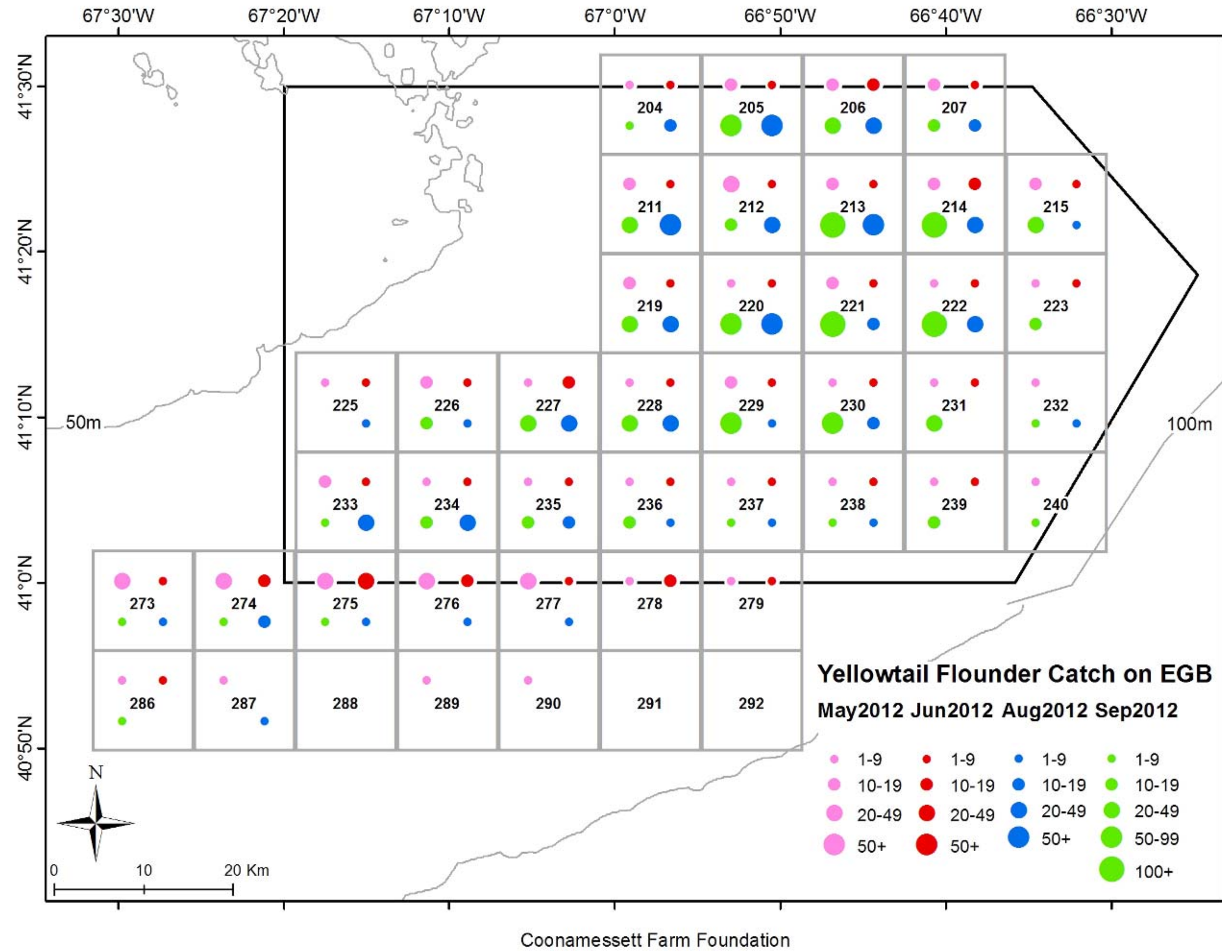
Appendix B



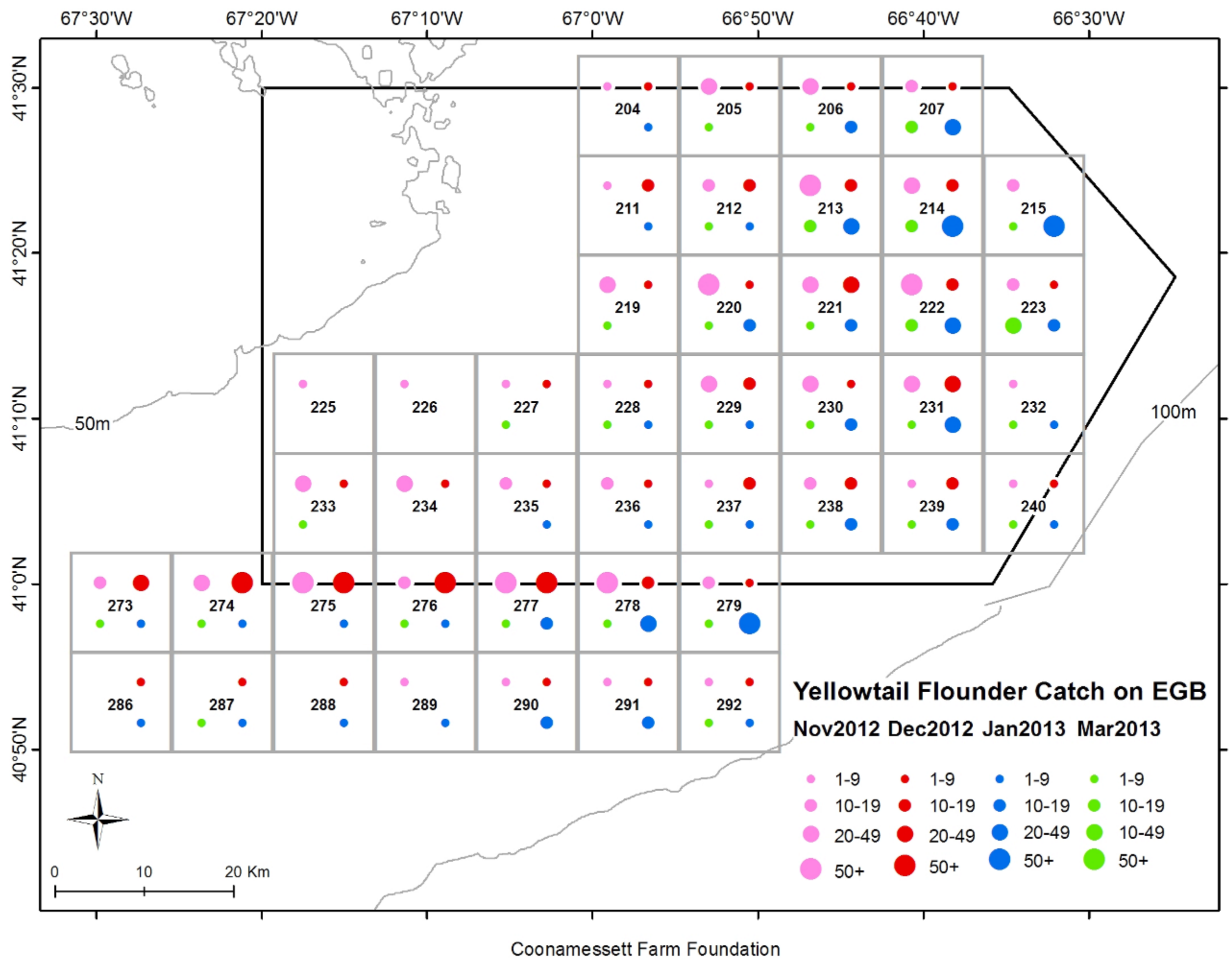
Appendix B Figure 1. Distribution of yellowtail flounder catch in WGB in May, June, August and September 2012. 50 and 100 m bathymetric lines are shown.



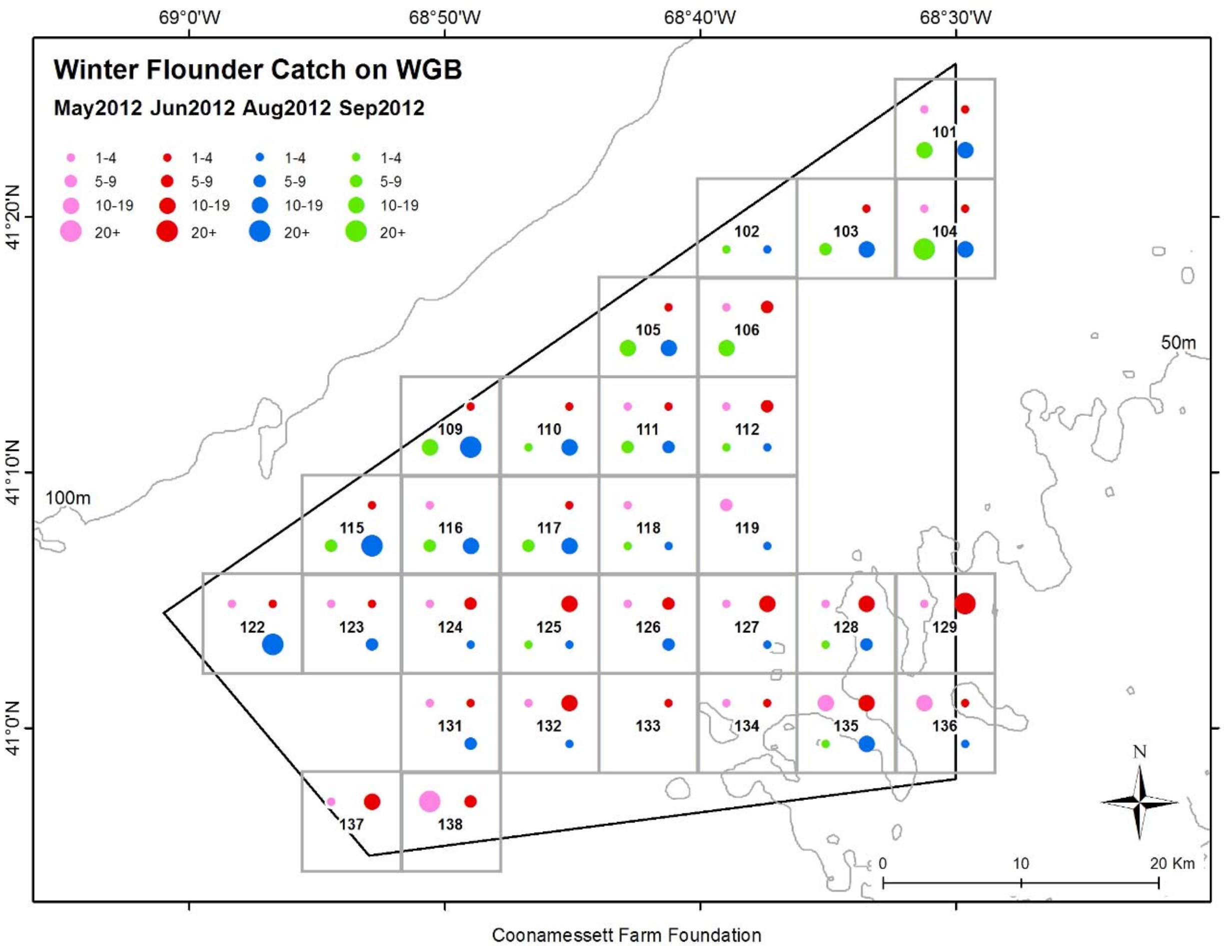
Appendix B Figure 2. Distribution of yellowtail flounder catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



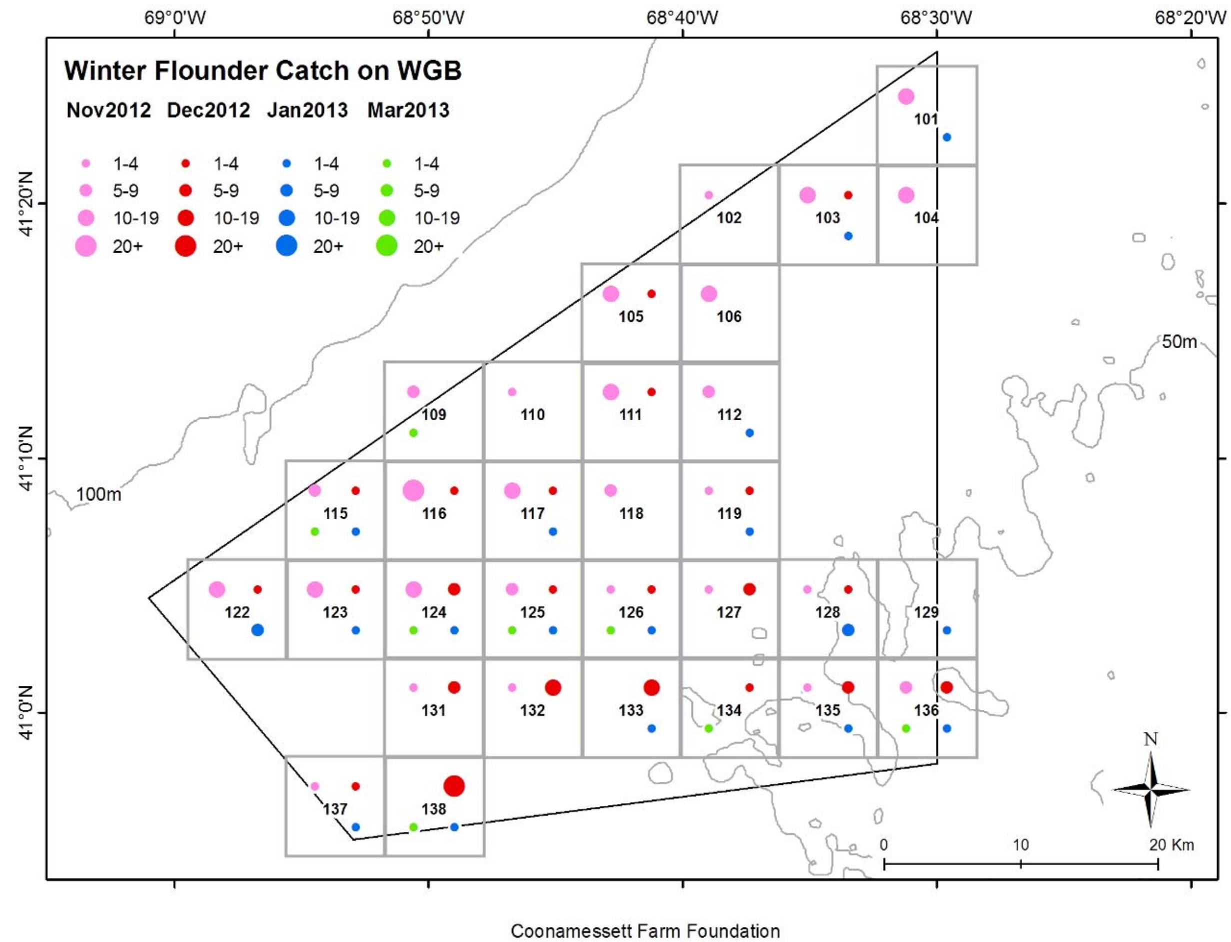
Appendix B Figure 3. Distribution of yellowtail flounder catch in EGB in May, June, August and September 2012. 50 and 100 m bathymetric lines are shown.



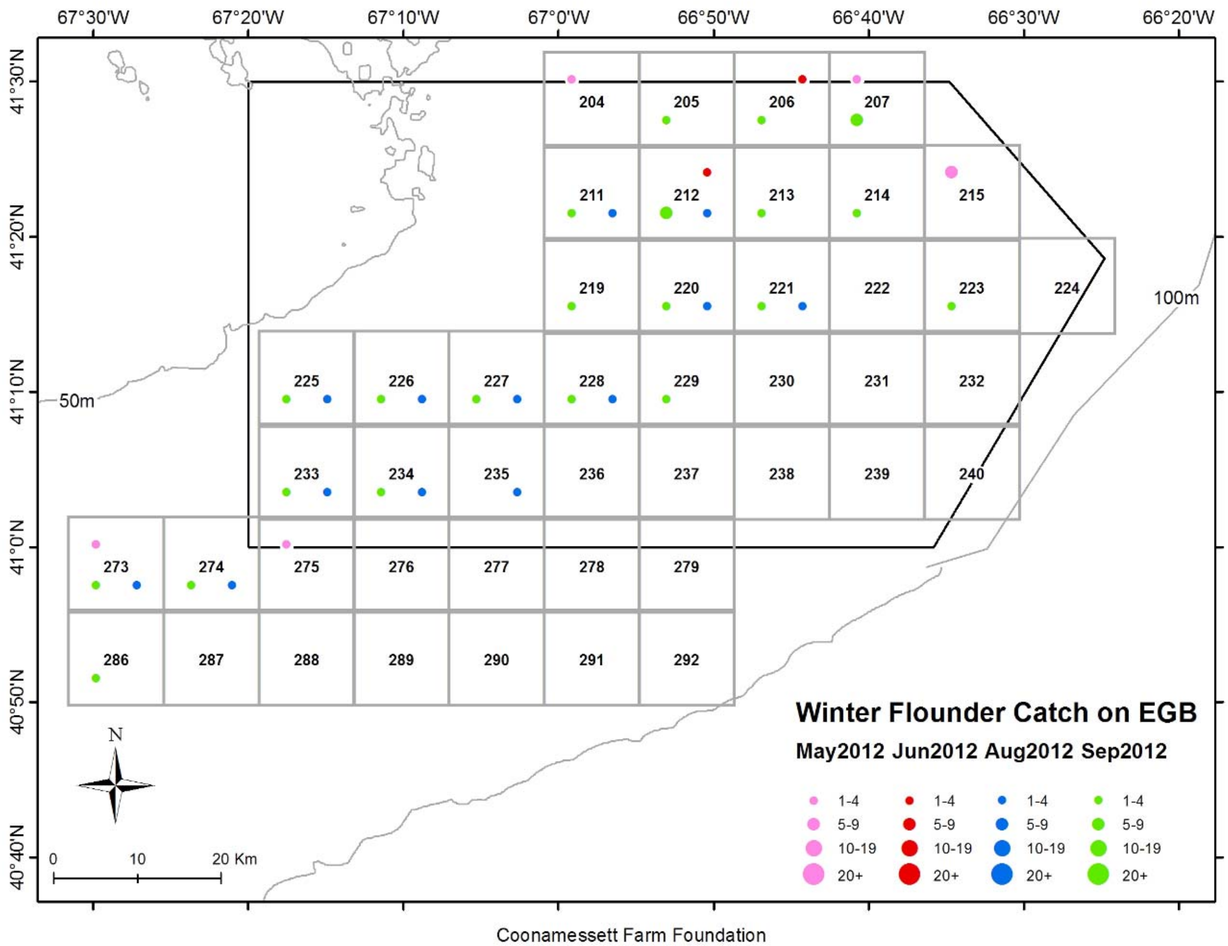
Appendix B Figure 4. Distribution of yellowtail flounder catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



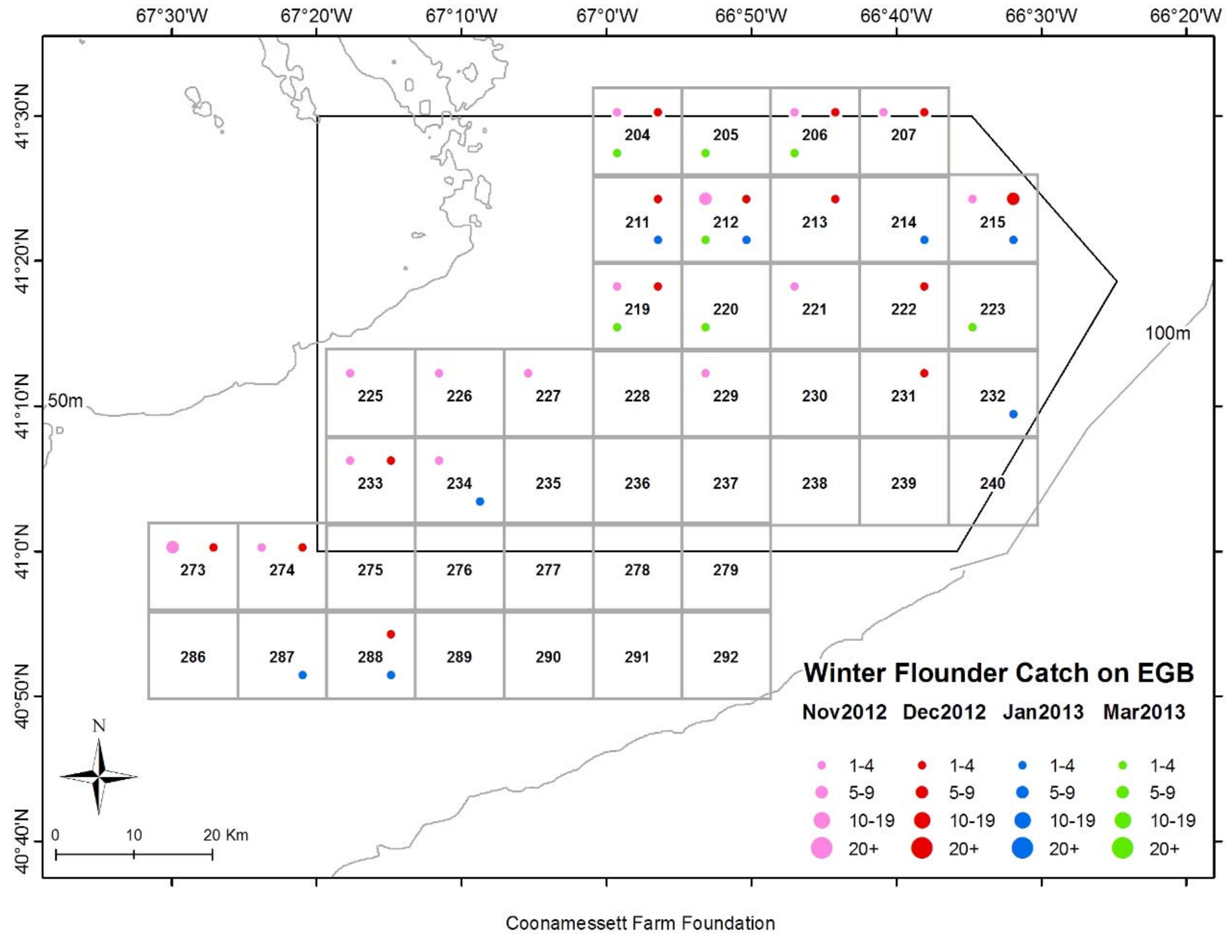
Appendix B Figure 5. Distribution of winter flounder catch in WGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



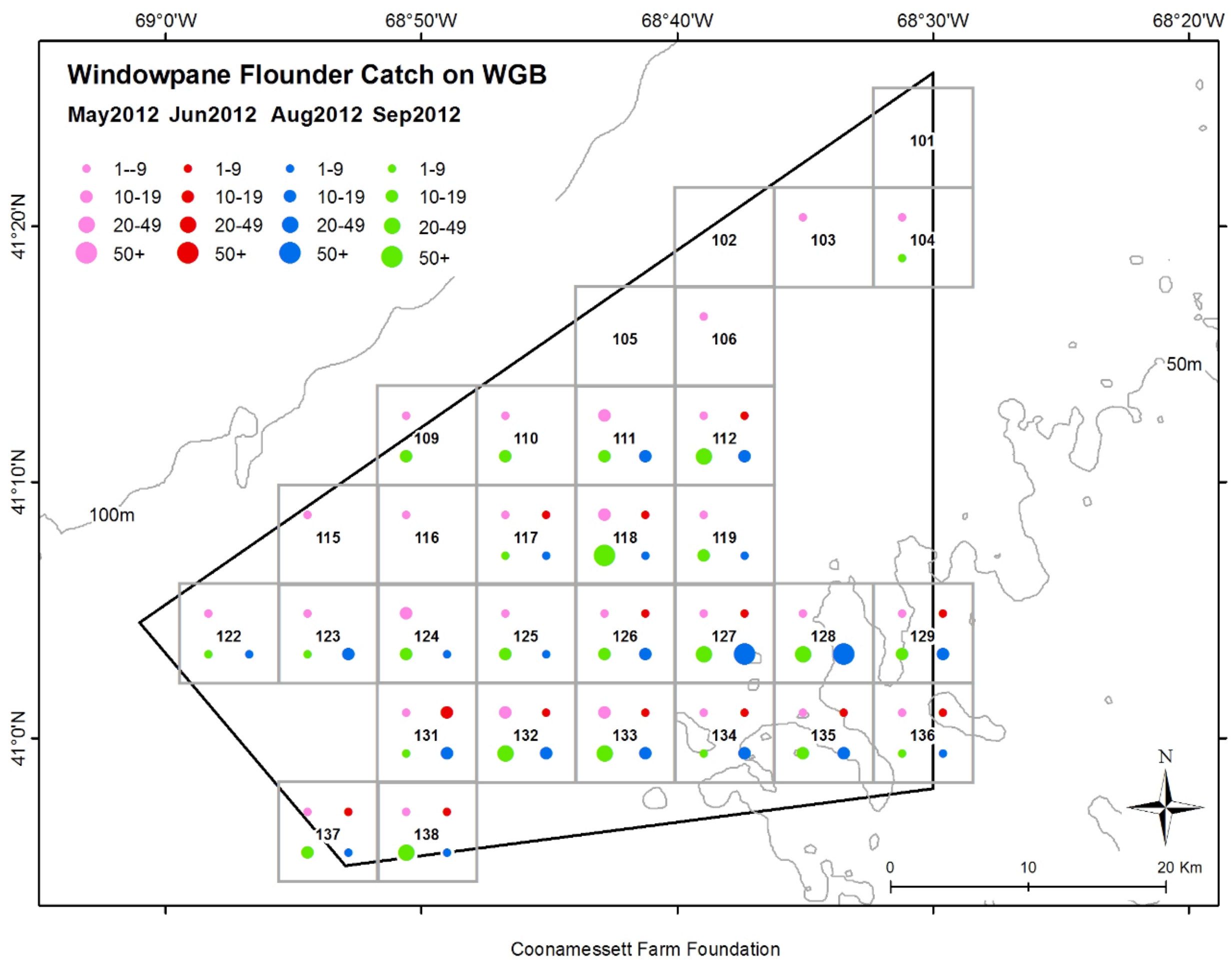
Appendix B Figure 6. Distribution of winter flounder catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



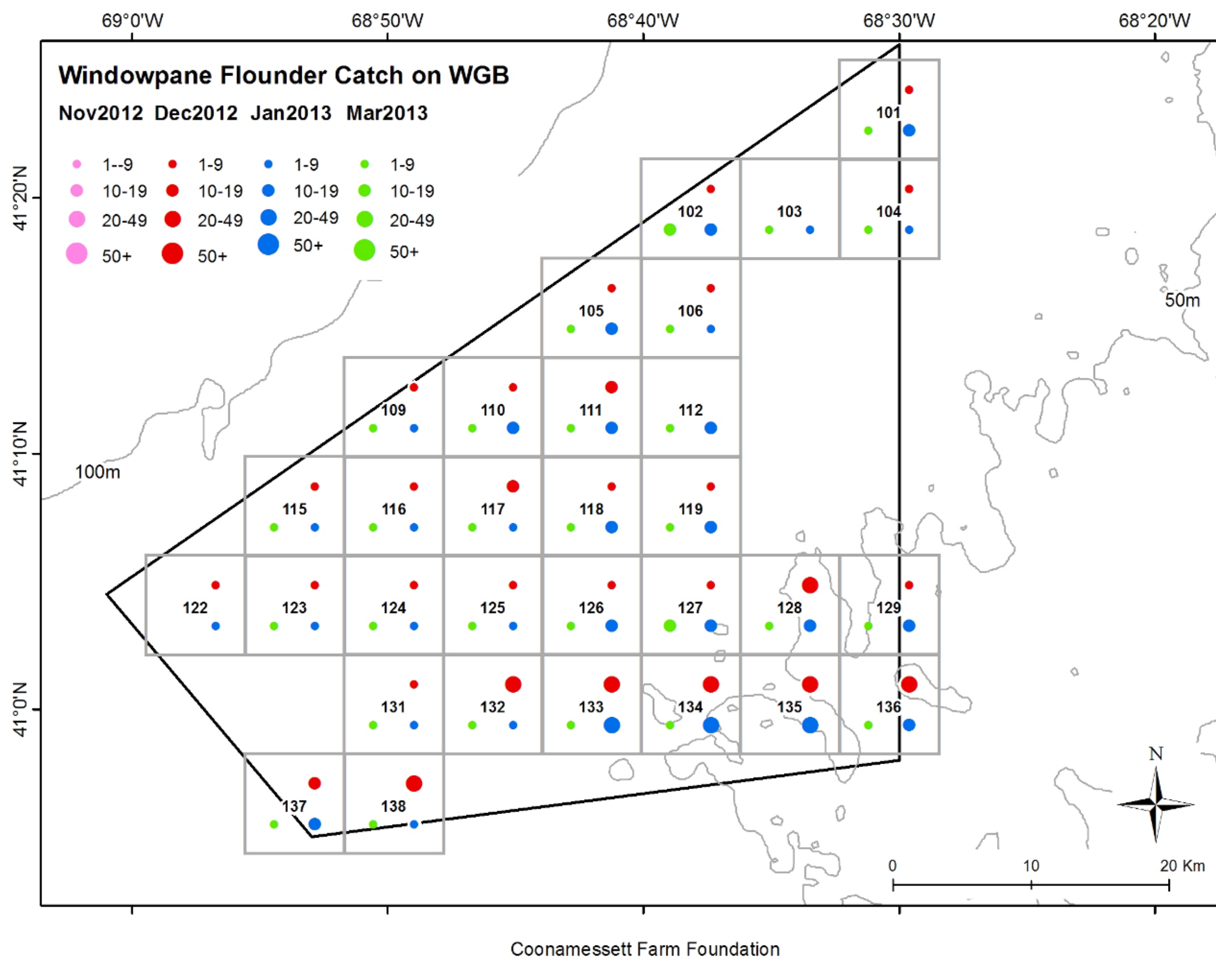
Appendix B Figure 7. Distribution of winter flounder catch in EGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



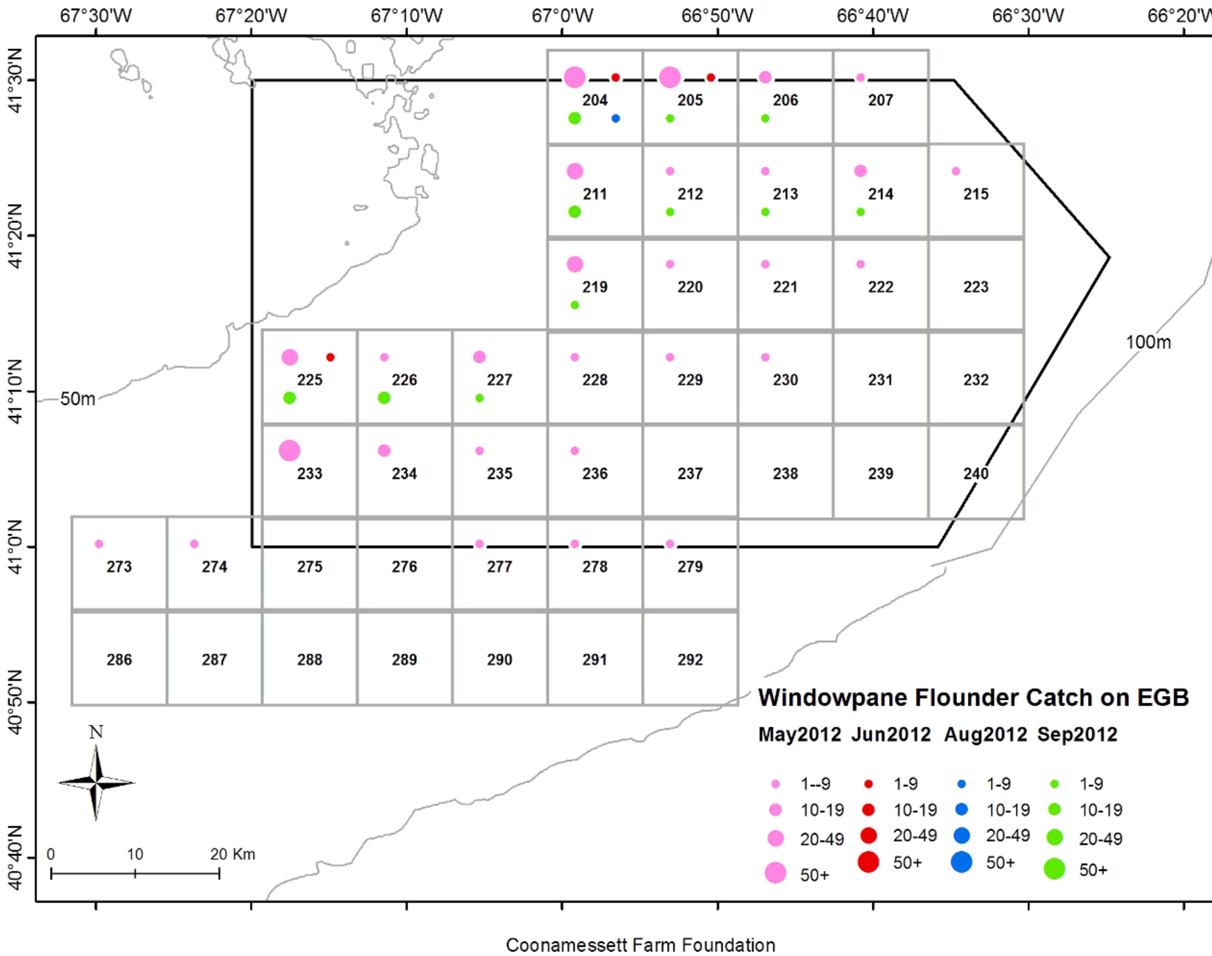
Appendix B Figure 8. Distribution of winter flounder catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



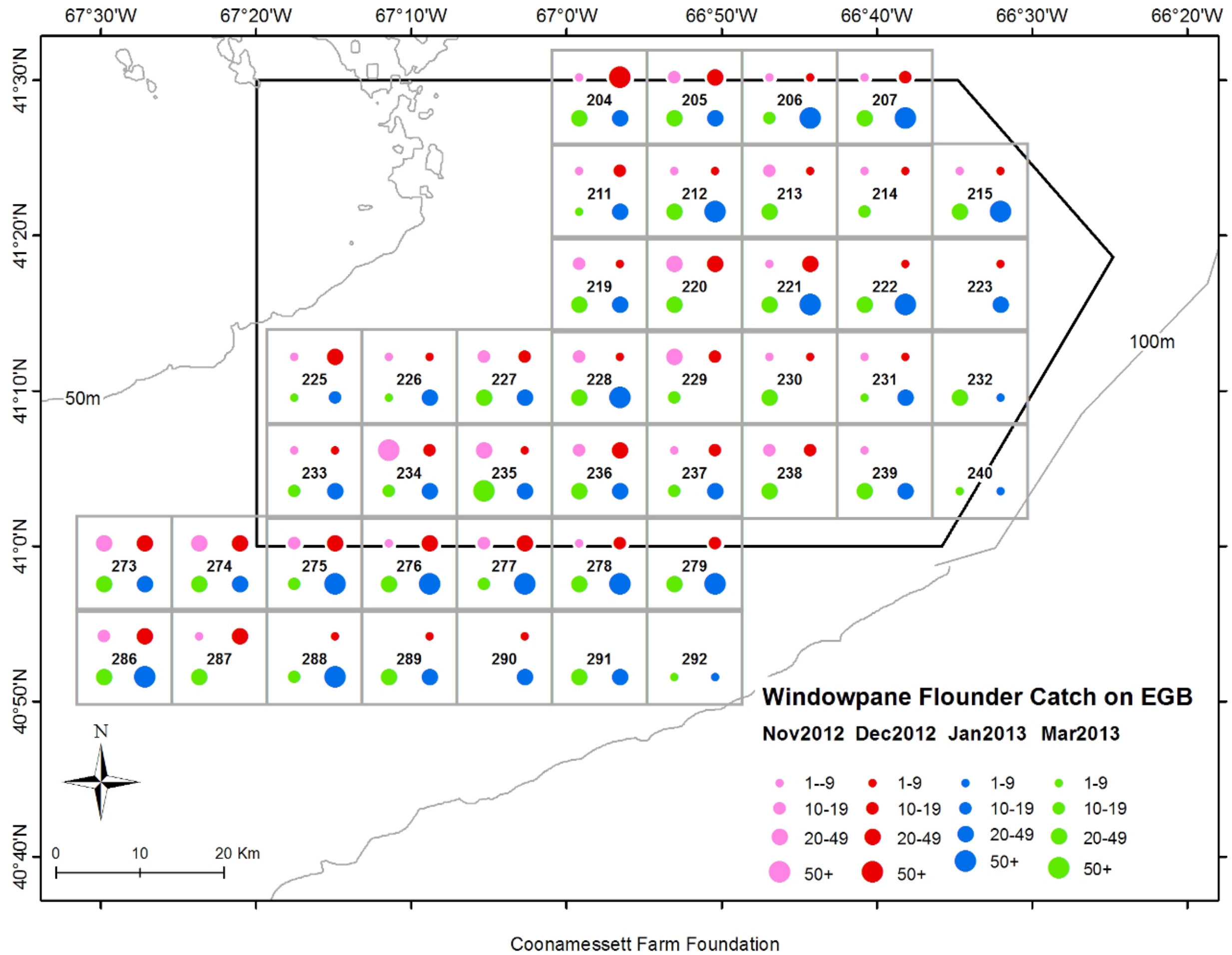
Appendix B Figure 9. Distribution of windowpane flounder catch in WGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



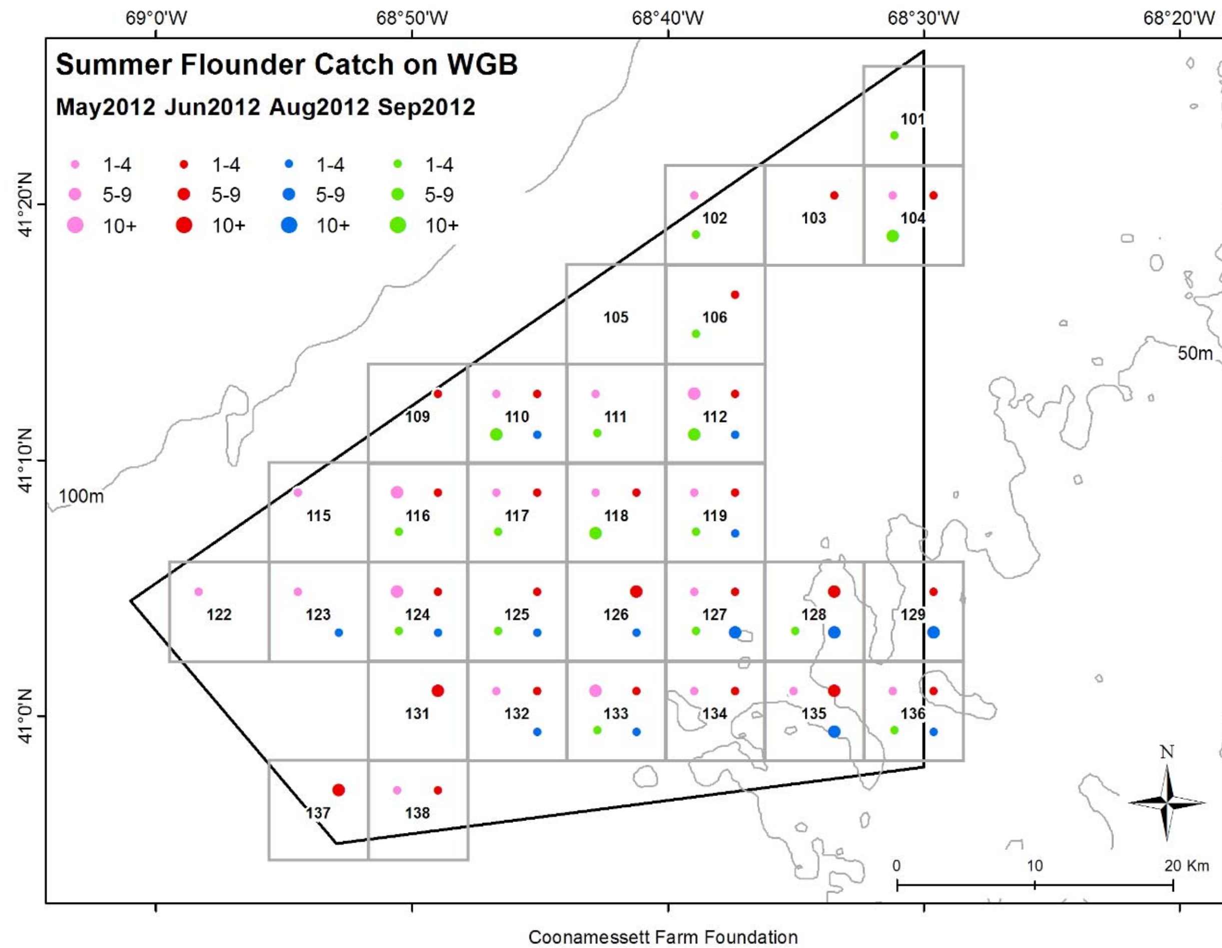
Appendix B Figure 10. Distribution of windowpane flounder catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



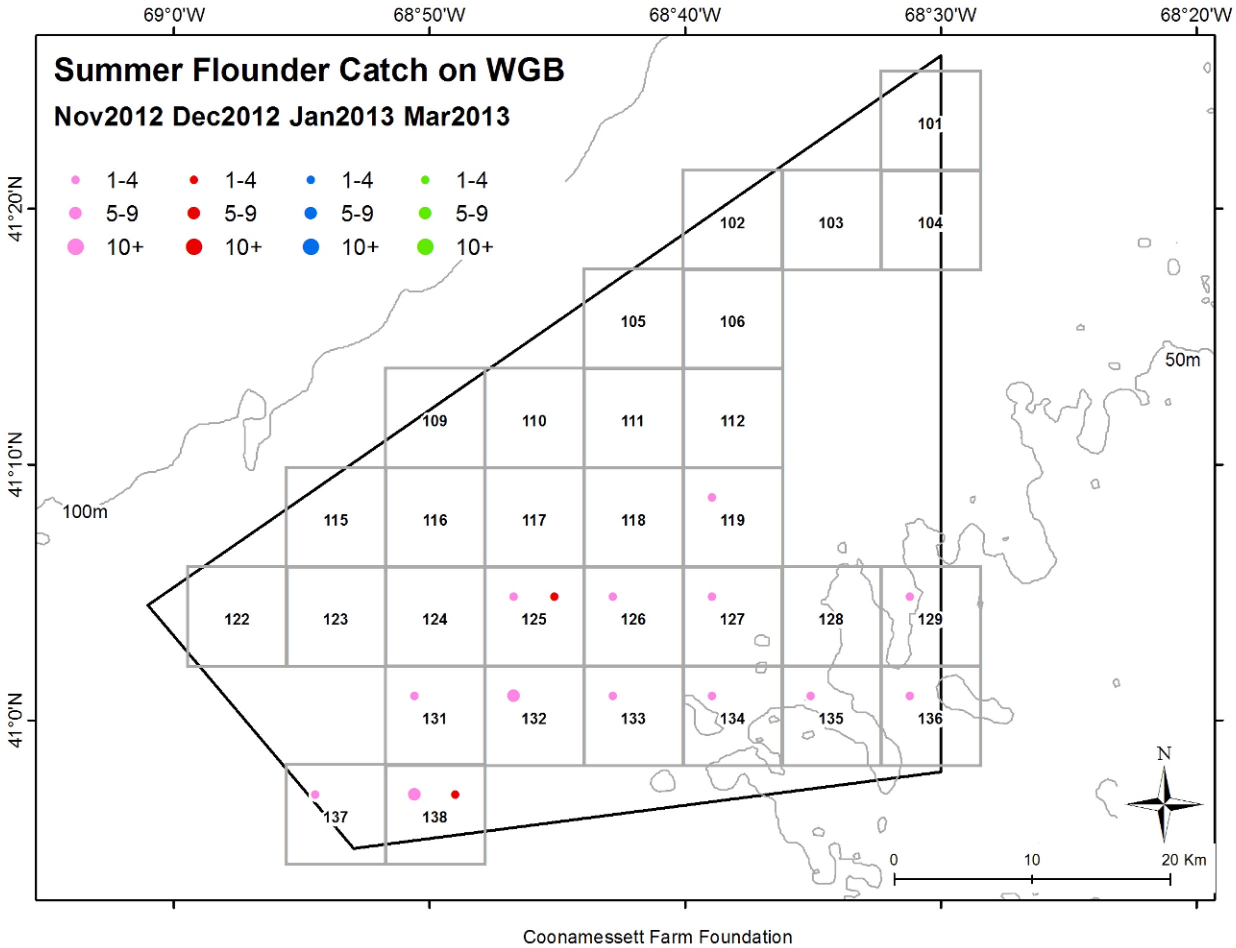
Appendix B Figure 11. Distribution of windowpane flounder catch in EGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



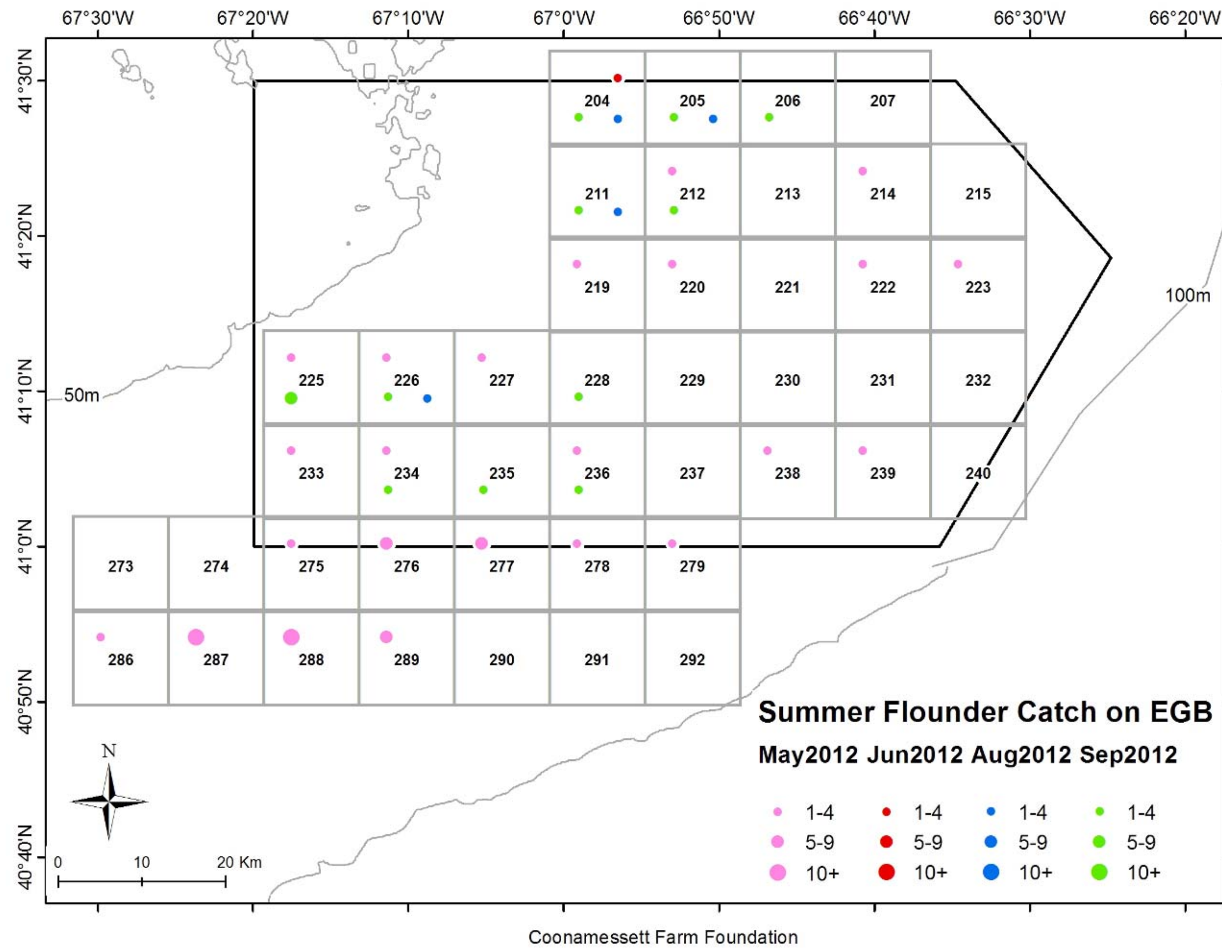
Appendix B Figure 12. Distribution of windowpane flounder catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



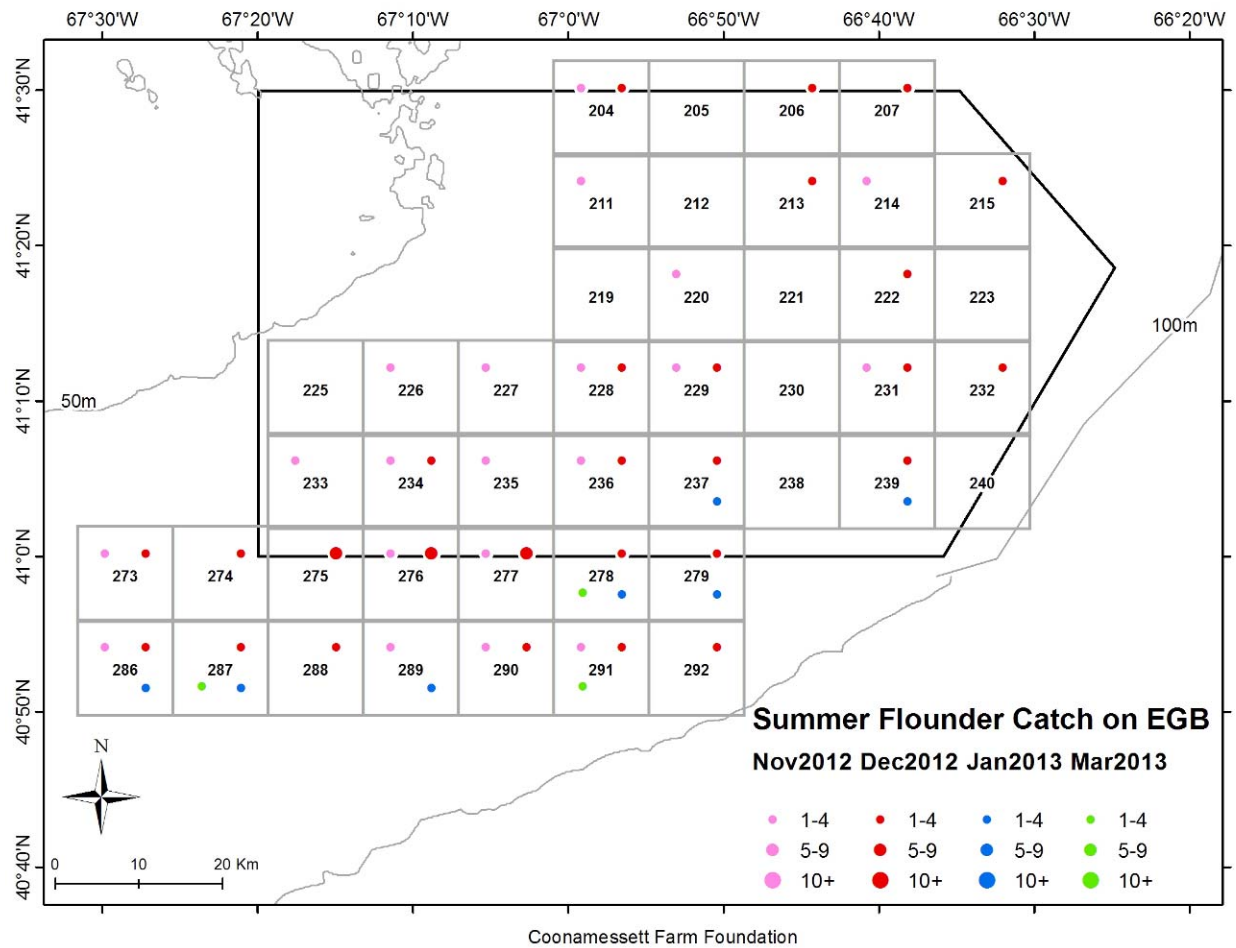
Appendix B Figure 13. Distribution of summer flounder catch in WGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



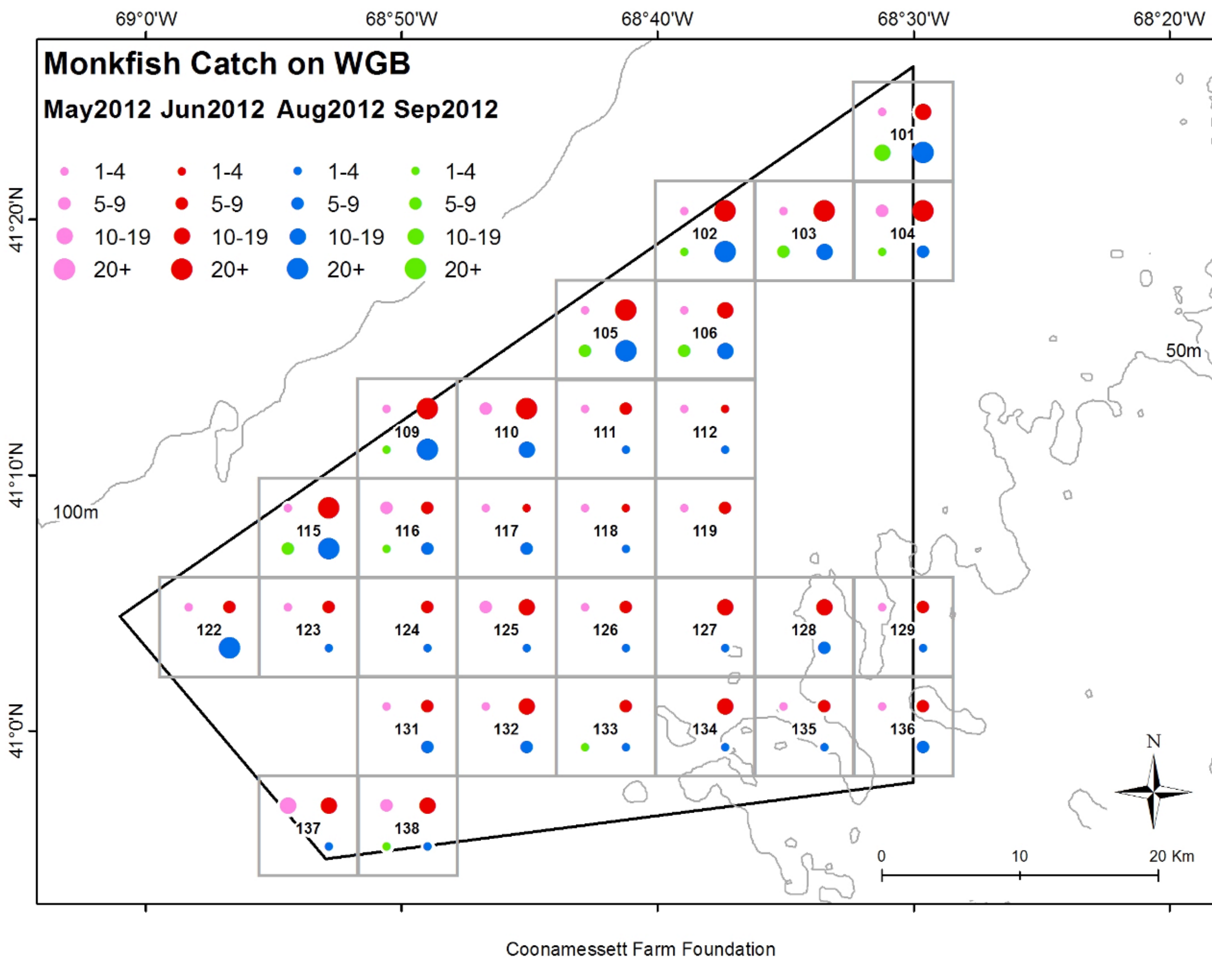
Appendix B Figure 14. Distribution of summer flounder catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



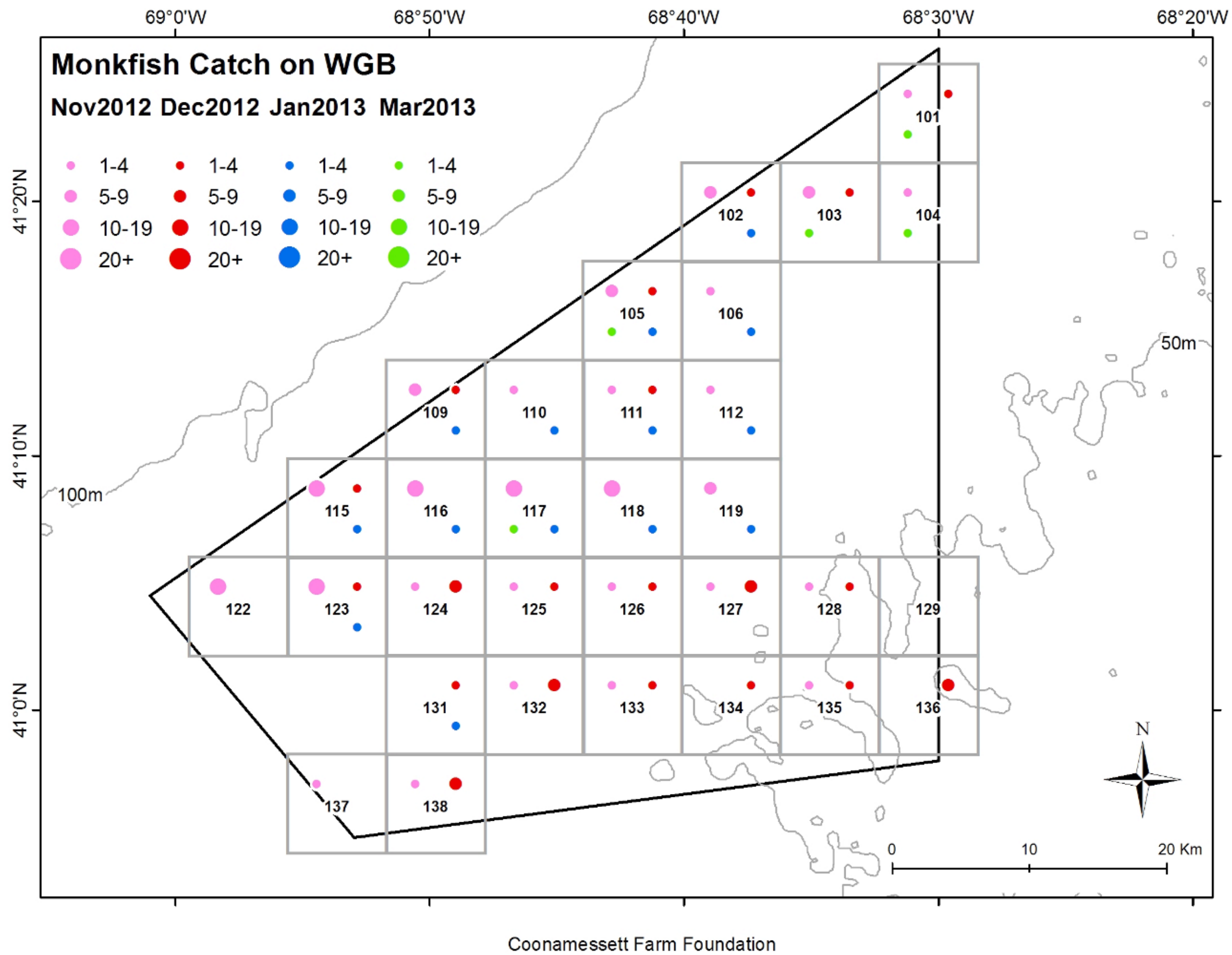
Appendix B Figure 15. Distribution of summer flounder catch in EGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



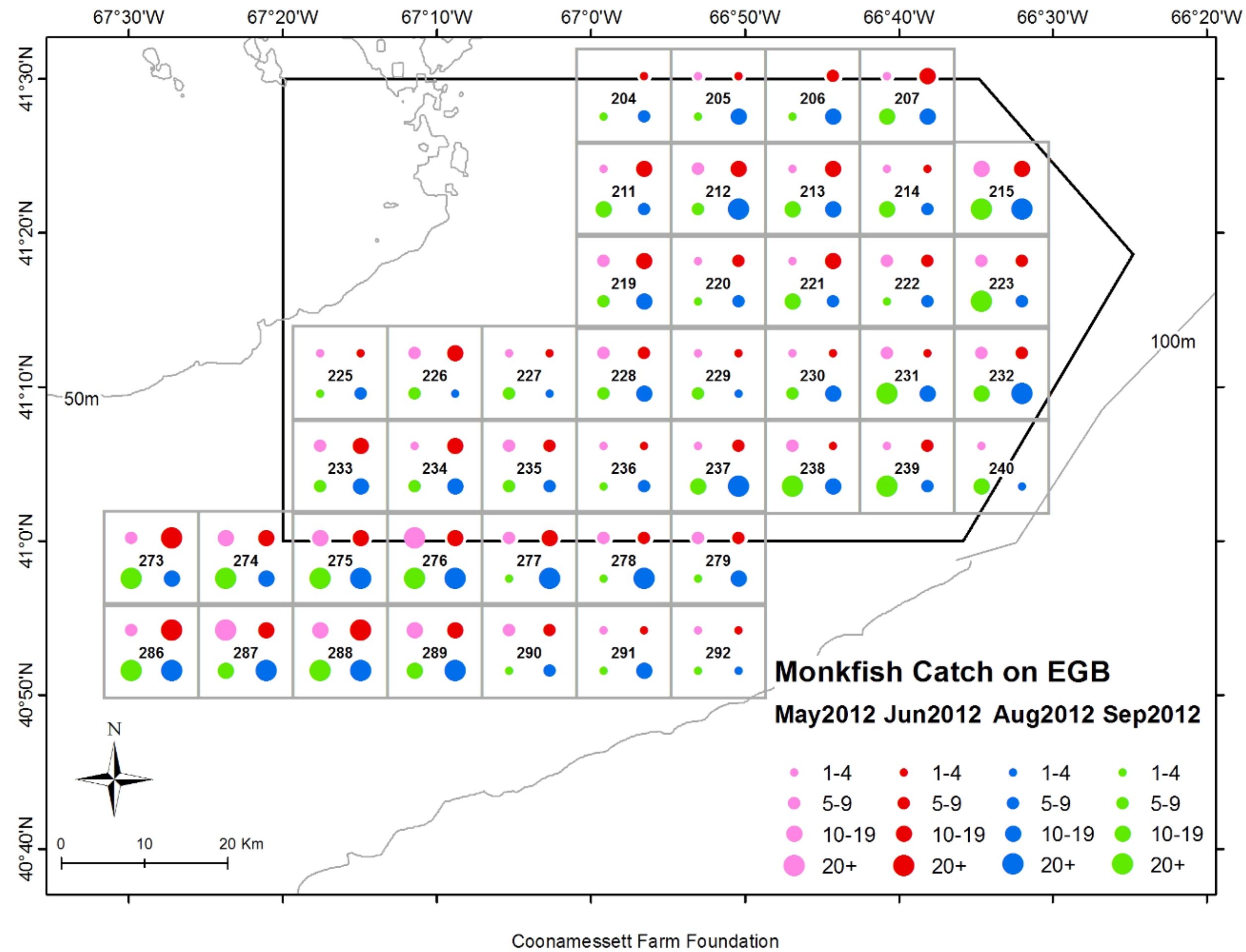
Appendix B Figure 16. Distribution of summer flounder catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



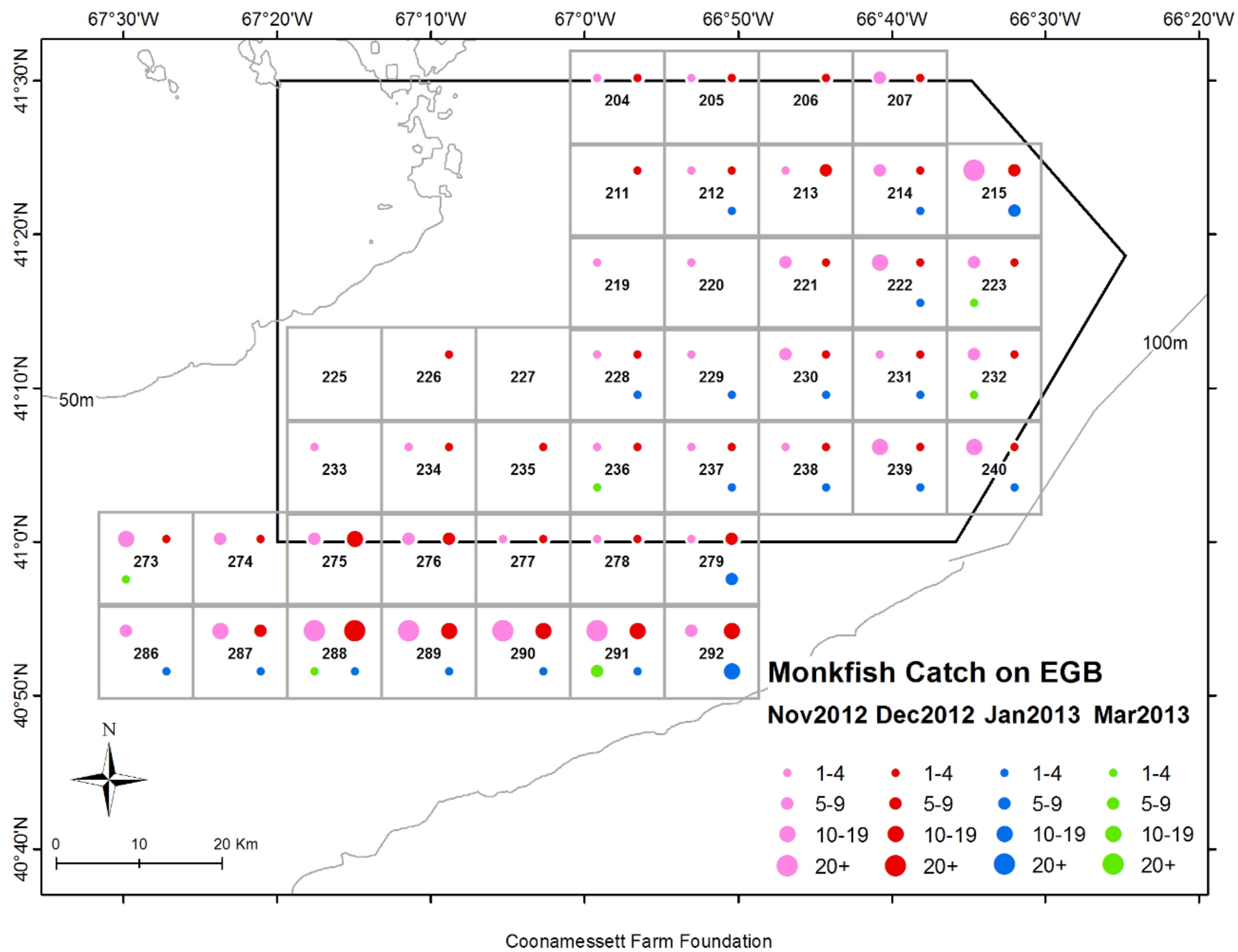
Appendix B Figure 17. Distribution of monkfish catch in WGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



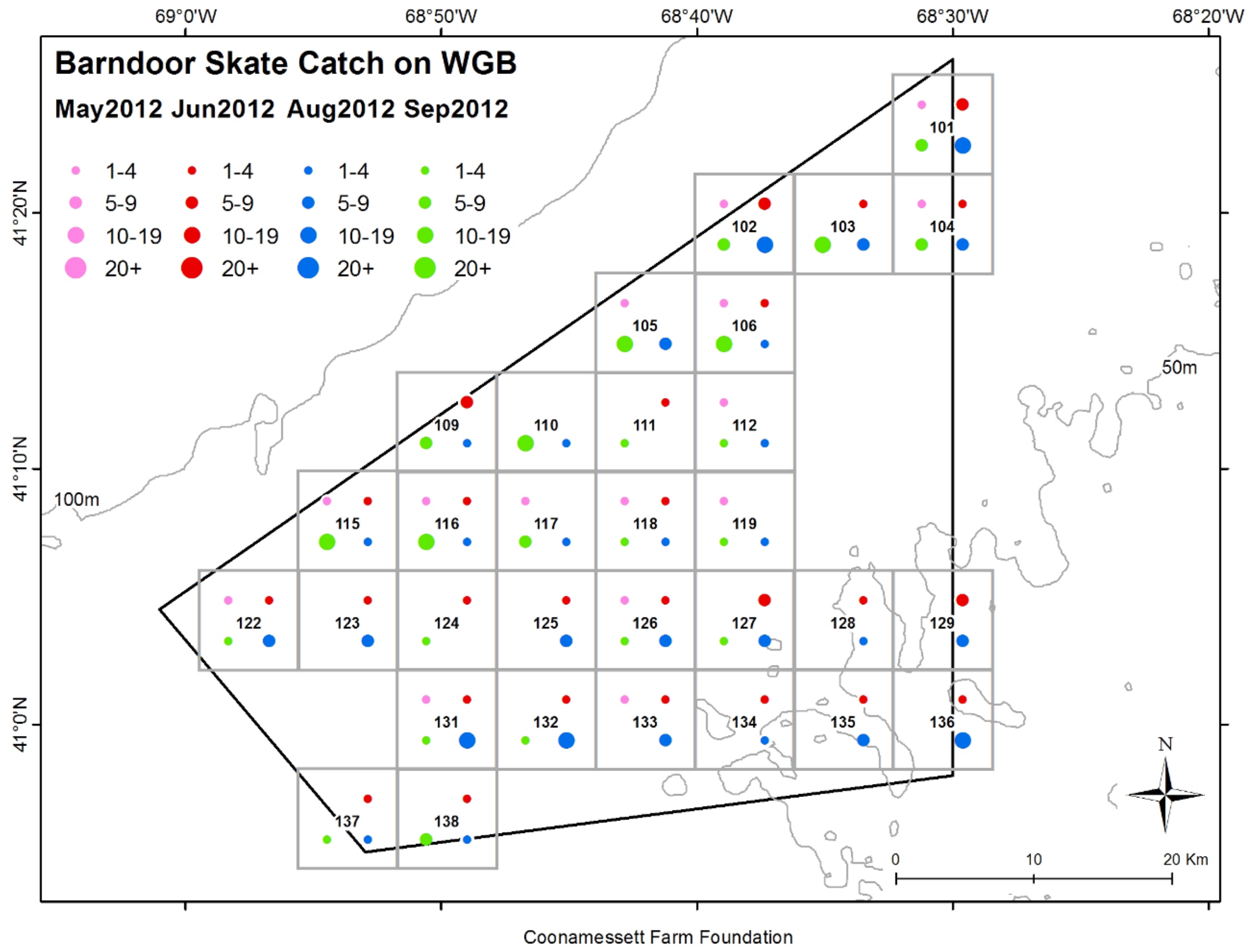
Appendix B Figure 18. Distribution of monkfish catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



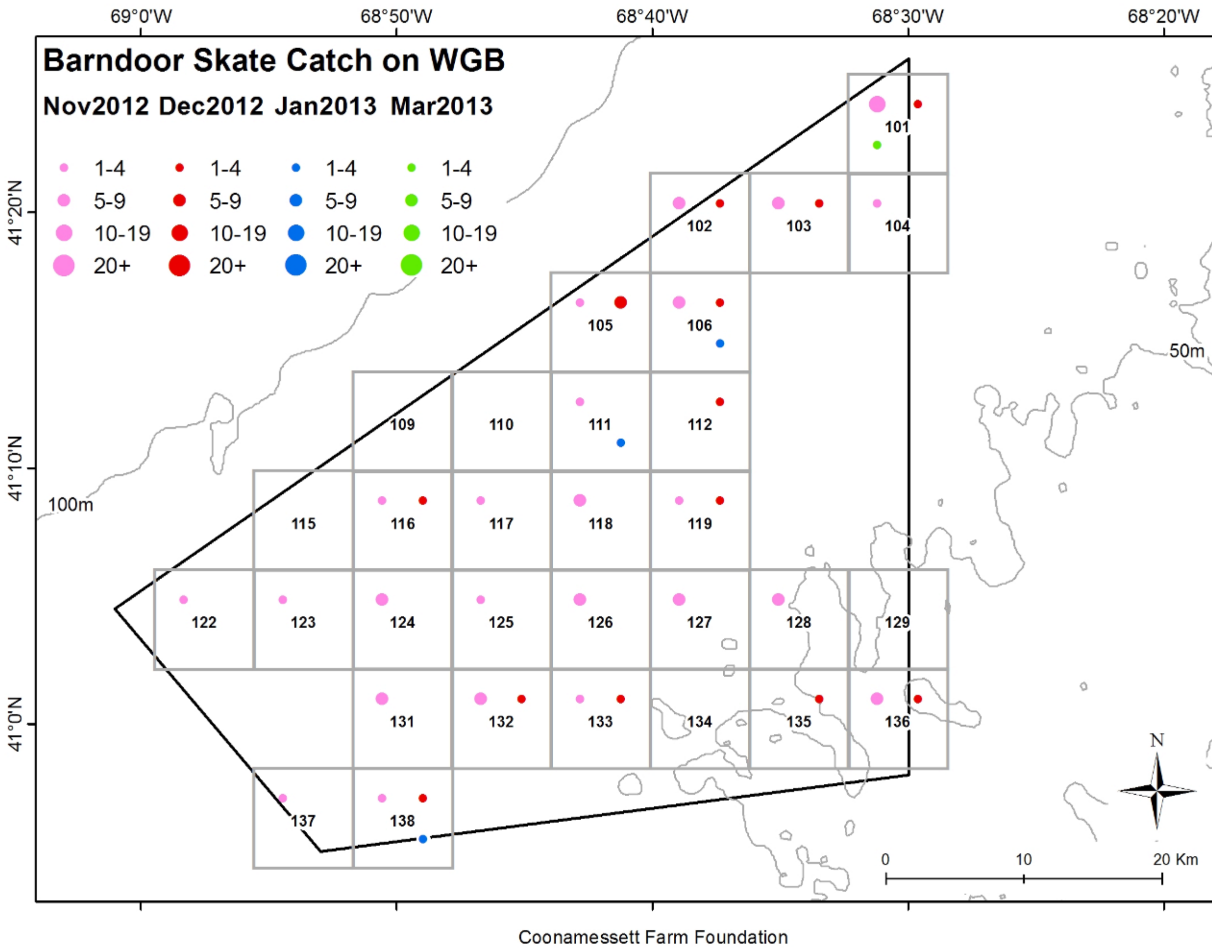
Appendix B Figure 19. Distribution of monkfish catch in EGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



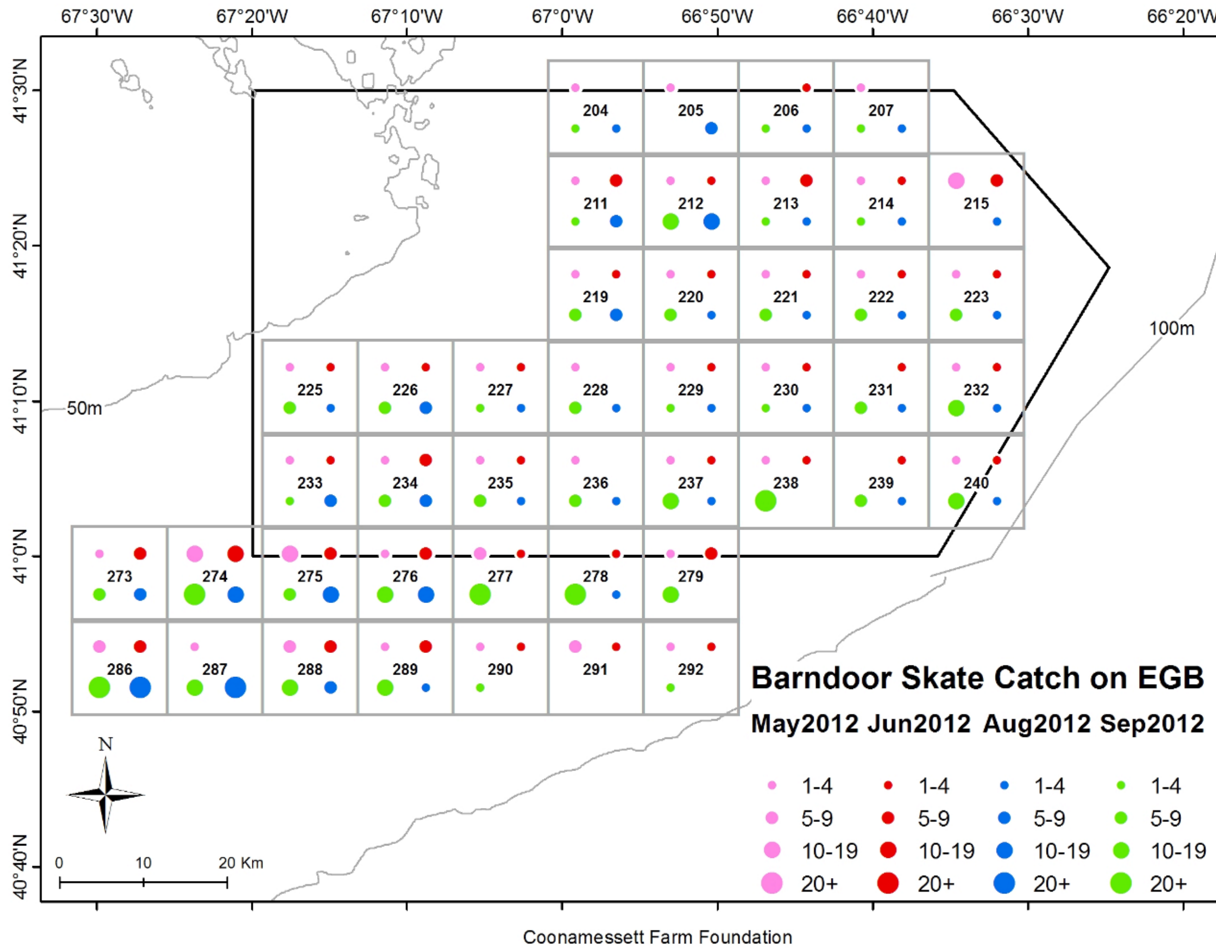
Appendix B Figure 20. Distribution of monkfish catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



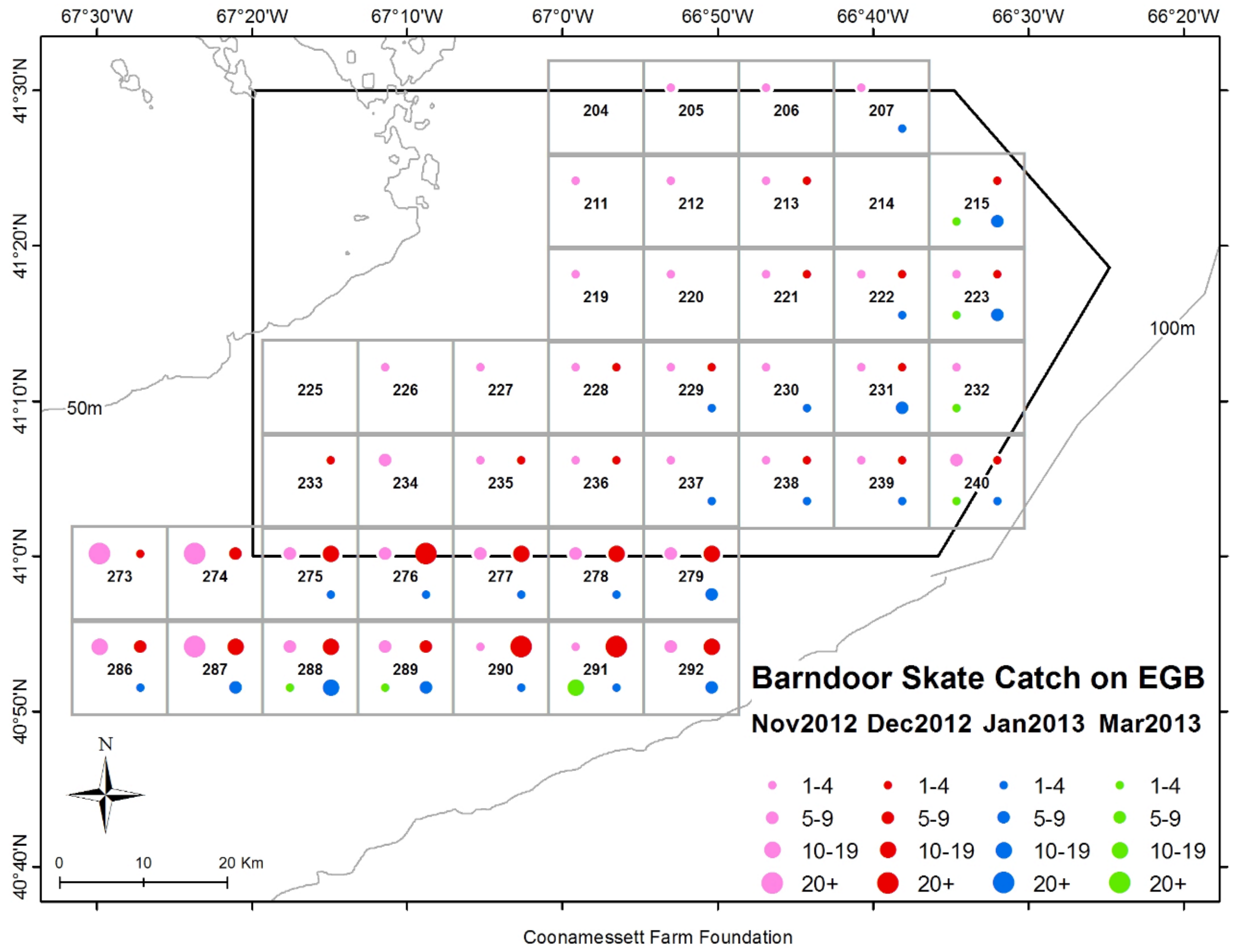
Appendix B Figure 21. Distribution of barndoor skate catch in WGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



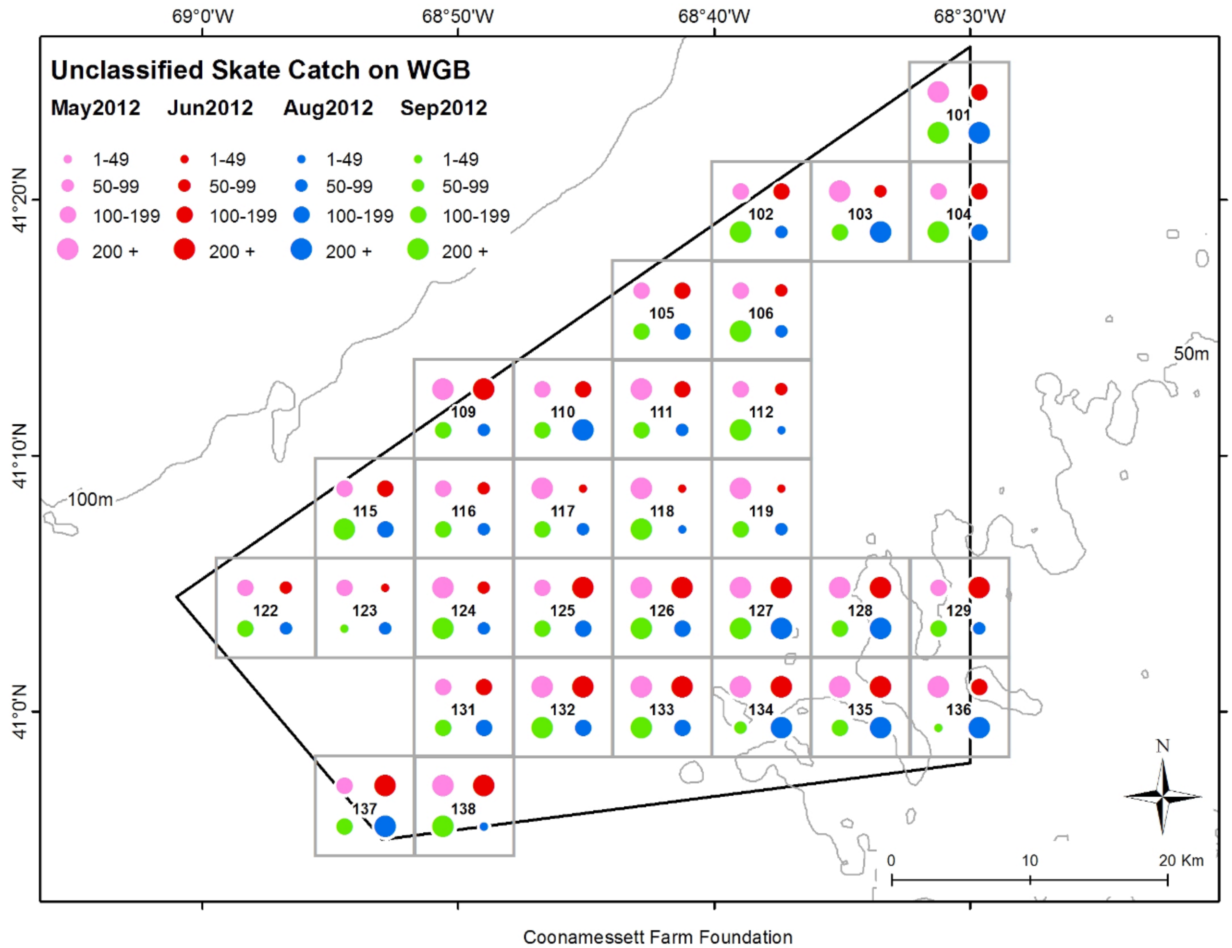
Appendix B Figure 22. Distribution of barndoor skate catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



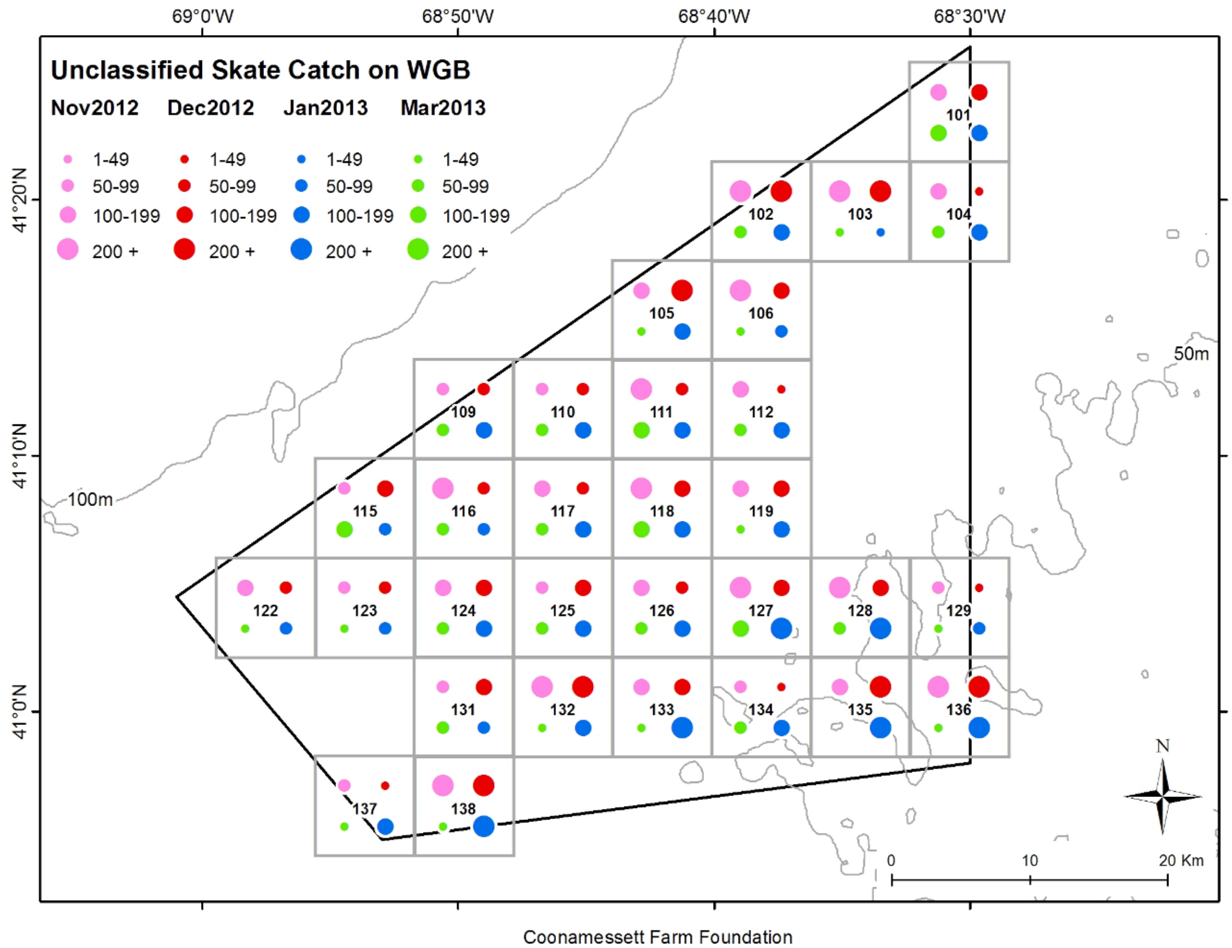
Appendix B Figure 23. Distribution of barndoor skate catch in EGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



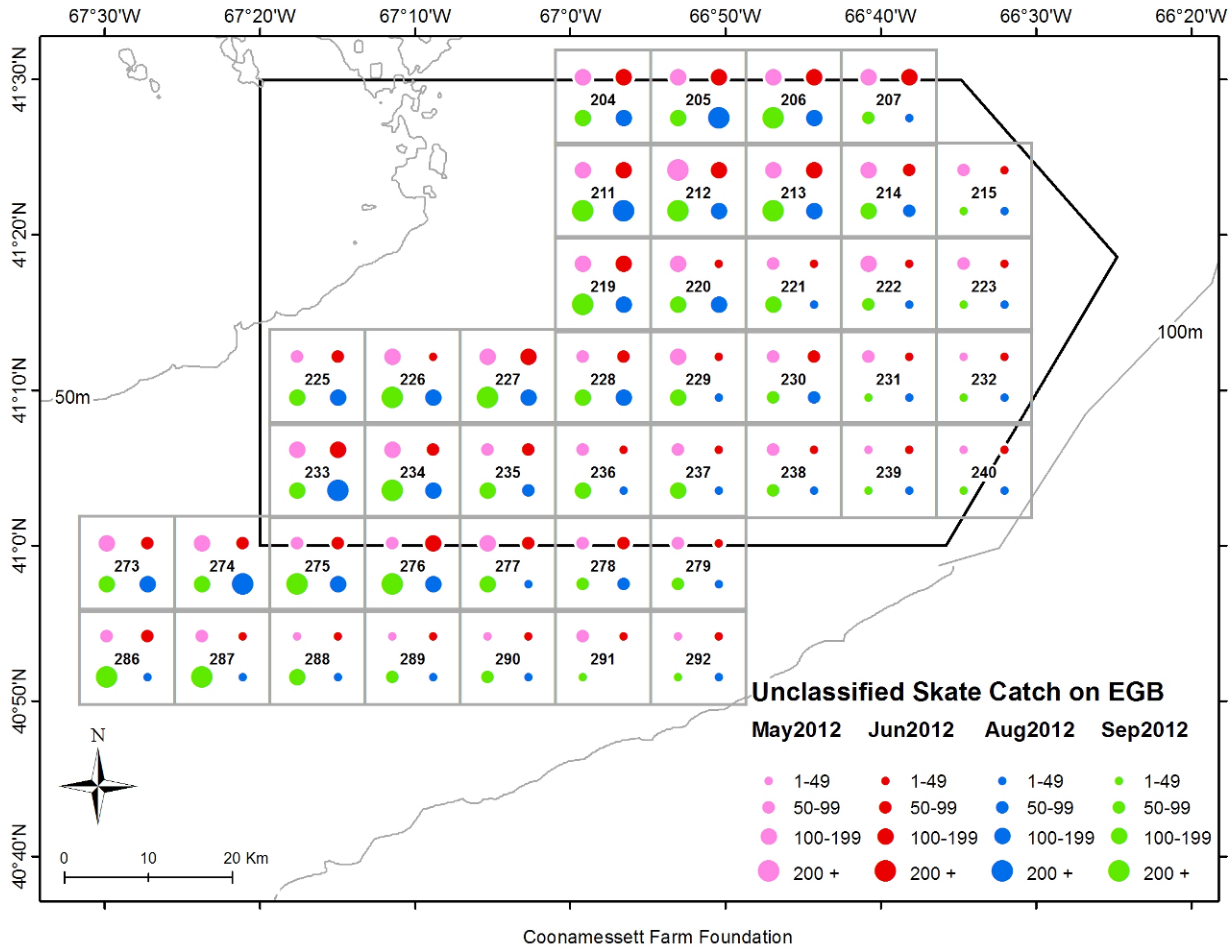
Appendix B Figure 24. Distribution of barndoor skate catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



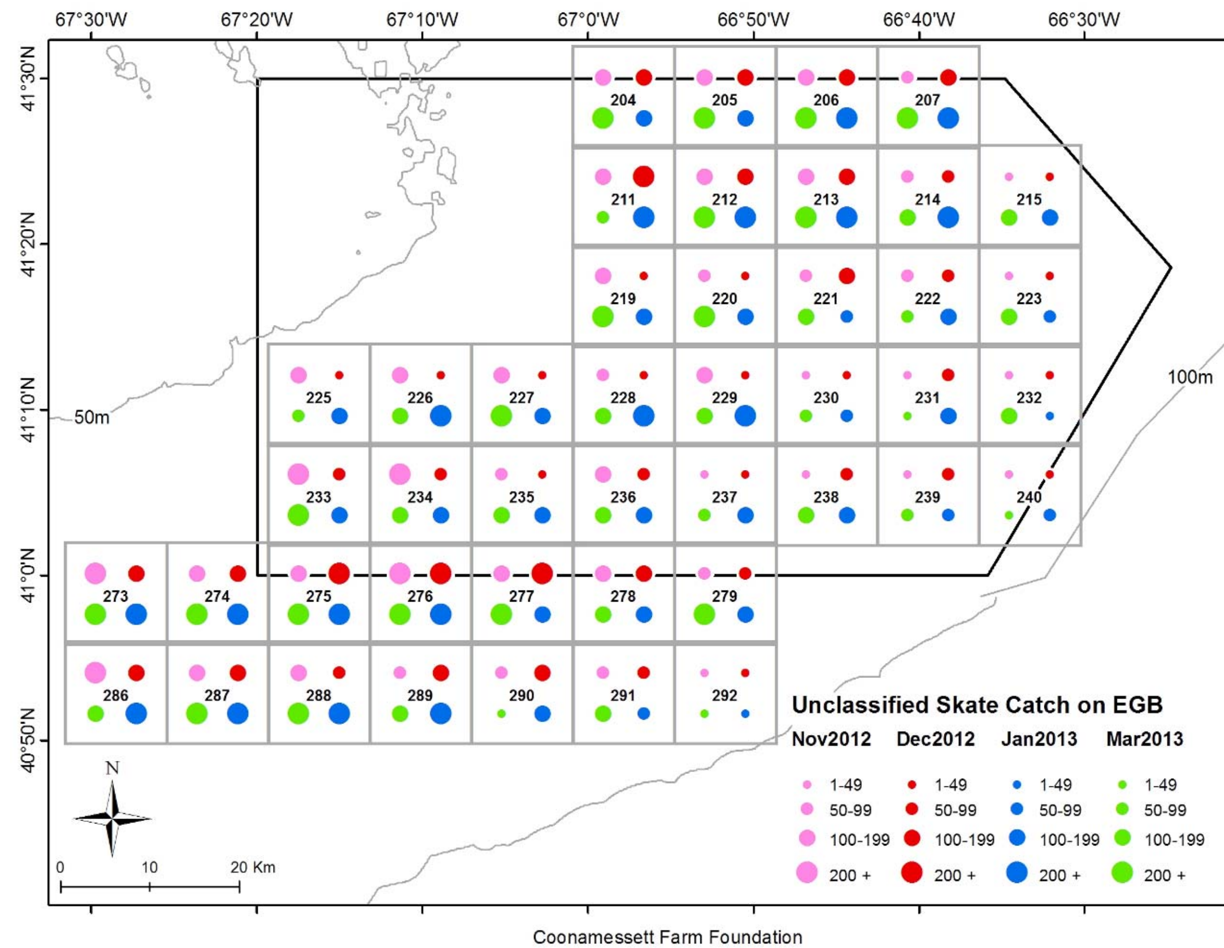
Appendix B Figure 25. Distribution of unclassified skate catch in WGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



Appendix B Figure 26. Distribution of unclassified skate catch in WGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.



Appendix B Figure 27. Distribution of unclassified skate catch in EGB in May, June, August, and September 2012. 50 and 100 m bathymetric lines are shown.



Appendix B Figure 28. Distribution of unclassified skate catch in EGB in November and December 2012, January and March 2013. 50 and 100 m bathymetric lines are shown.