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Proposed Vessel Calibration Studies for NOAA Ship Henry B. Bigelow

by NEFSC Vessel Calibration Working Group

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Introduction

Standardized bottom trawl surveys have been an integral component of Northeast Fisheries Science Center ecosystem monitoring activities since the autumn of 1963 (Azarovitz et al. 1997). The autumn survey was supplemented by a spring survey starting in 1968 and a winter series was initiated in 1992. These surveys are designed to characterize spatial and temporal changes in the abundance of fish and macroinvertebrate species vulnerable to the sampling gear, demographic attributes of these species, and ecological interactions based on food habits studies and other observations. A stratified random sampling design has been employed for all surveys and biological samples are collected using a multi-stage cluster sampling design. Observations on lower trophic levels and oceanographic properties are also collected in conjunction with these surveys and in complementary ecosystem monitoring cruises. The NOAA Ship *Albatross IV* (*Albatross*) has been the principal research vessel employed throughout the series although the NOAA Ship *Delaware II* (*Delaware*) has also been used in selected bottom trawl surveys. An extensive series of calibration experiments has been undertaken to test for vessel differences and permit conversion of *Delaware* catches to *Albatross* catch units to account for these changes (Byrne and Fogarty 1985; Byrne and Forrester 1991). For general overviews of the design and analysis of comparative fishing trials, see Bergh et al. (1990) and Pelletier (1998).

The *Albatross* is scheduled to be replaced by the NOAA Ship *Henry B. Bigelow* (*Bigelow*) in 2008, necessitating a new series of vessel calibration studies. The objective of the proposed experiments is to develop *Bigelow-Albatross* conversion coefficients to maintain consistent time series for the purpose of meeting stock assessment and ecosystem monitoring requirements. In addition to the vessel replacement, a change in the trawl gear used in standardized surveys from a Yankee No. 36 to a four-seam bottom trawl will be made at the recommendation of the MAFMC/NEFMC Trawl Advisory Panel (Brown 2007). Changes in selected sampling protocols, including tow speed and duration for the *Bigelow* are also recommended by the panel in conjunction with the gear change.

Background Data Analyses

The *Bigelow* is currently undergoing final outfitting and performance testing. Accordingly, it has not yet been possible to undertake pilot studies to inform the design and operational details of the proposed calibration experiments. As a prelude to these studies, we have attempted to assemble any relevant information available to assess possible effects attributable to the net design and sweep configuration to be used and the implications of small-scale spatial heterogeneity for the experimental design to guide the present planning exercise.

Here, we review existing information on catch characteristics of the new four-seam trawl in comparison to the Yankee No. 36 trawl in trials conducted using the *Albatross* and *Delaware*. Although the number of observations available to make these comparisons is limited, they provide preliminary information on the possible magnitude of differences in expected catches. We also review information available on patterns of spatial heterogeneity based on a previous set of site-specific studies to assess the implications of spatial offsets in trawl paths in paired tows.

Four-seam–Yankee No. 36 Net Comparisons

A total of thirty-one valid paired tows were made between the *Albatross* towing the Yankee No. 36 bottom trawl using standard towing protocols at 3.8 knots (7.0 km hr^{-1}) for 30 minutes and the *Delaware* towing the four-seam bottom trawl with rockhopper sweep at a speed of 3.0 knots (5.6 km hr^{-1}) for 20 min during the spring 2006 bottom trawl survey. The stations were on Georges Bank, the Great South Channel and in the Gulf of Maine. In eighteen of these paired tows, the vessels towed parallel tracks at a distance of 0.25 n mi (~ 460 m) apart. In the remaining thirteen tows, exact temporal pairing was not possible and the *Delaware* towed at the station within 24 hr of the *Albatross* tow. For the purposes of these initial analyses, these tow types were combined. It is expected that this will increase the variance in the estimates. To account for differences in tow speed and distance covered, the catches were standardized to a common distance over ground.

We are interested in assessing the combined vessel/gear effect on catch rates with the objective of providing a first approximation to the magnitude of potential differences to be expected in the planned calibration experiments to be conducted between the *Albatross* and *Bigelow*. It is recognized that the performance characteristics of the four-seam net when deployed from the *Bigelow* may differ substantially from the results obtained when towed by the *Delaware* and the following provides only a rough guide. We present results for the catch in weight and make no attempt to develop length-specific conversion coefficients because of the relatively low sample sizes available. We further make the simplifying assumption that the catches of the two vessels are drawn from the same underlying distribution. In the planned calibration experiments and subsequent analyses, these restrictions are relaxed.

We developed calibration coefficients for selected species to convert the *Delaware* four-seam catches to expected *Albatross* Yankee No. 36 catches. We will index the *Delaware* four-seam combination as D and the *Albatross* Yankee No. 36 combination as A. Again for simplicity, here and throughout this document we will not index for species in presenting estimators. The expected *Delaware* catch at the ith station (C_{iD}) is given by:

$$E(C_{i,D}) = q_D \lambda_i = \mu_{i,D}.$$

where q_D is the survey catchability coefficient for the *Delaware* and λ_i is the fish density at station i. Similarly the expected *Albatross* catch is:

$$E(C_{i,A}) = q_A \lambda_i = \gamma \mu_{i,D}.$$

where γ is the calibration coefficient for converting *Delaware* four-seam to *Albatross* Yankee No. 36 catch units. The conversion coefficient is given by the ratio of the catchability coefficients for the *Albatross* and *Delaware*:

$$\gamma = \frac{q_A}{q_D}.$$

We adopted the quasi-likelihood estimator defined by Pelletier (1998) for estimating the conversion coefficients in this illustration. Under the assumption of a common underlying distribution and a quadratic mean-variance relationship, the conversion coefficient can be developed using a ratio estimator based on the sum of catches for each vessel/gear combination. We estimated the standard error of the conversion coefficient using the bootstrap procedure recommended by Pelletier (1998) in which the selection for re-sampling is made on the paired observations.

For the species examined, the *Delaware*/four-seam *Albatross*/Yankee No. 36 conversion coefficient indicated substantial differences in expected catch levels (Table 1). The difference ranged from a factor of 1.75 higher for the *Delaware*/four-seam for alewife to a factor of 11.6 for goosefish. With the limited number of paired tows available, the relative precision of the estimates of the conversion coefficients varied substantially (Table 1), largely as a function of the number of stations at which the species was obtained but also depending on factors such as schooling behavior and patchiness in distribution patterns . We also note that there is asymmetry in the number of cases in which the species was caught by one vessel but not the other (Table 1) with the *Delaware*/four-seam combination more often obtaining the species at locations where the *Albatross* did not. This effect was most pronounced for goosefish (Table 1).

If the performance of the four-seam net is similar on the *Bigelow* as on *Delaware*, it appears that with the markedly increased sample sizes expected in the planned experiments, reasonably precise estimates of the conversion coefficients should be attainable for many species. However, when partitioned by length class and other factors (e.g. potential day-night differences), the number of available observations to estimate conversion coefficients may become limited for some species.

Table 1. Estimates of *Delaware*/four-seam to *Albatross*/Yankee No. 36 conversion coefficients, standard errors and 90% confidence intervals for thirty one paired tows conducted on Georges Bank and the Gulf of Maine. N_{Both} is the number of stations at which both vessels caught the species, N_{ALB} is the number of stations at which the species was caught only by *Albatross*, and N_{DEL} is the number of stations at which the species was caught only by *Delaware*.

Species	Conversion Coefficient	Std. Err.	90% Confidence Intervals	N_{Both}	N_{ALB}	N_{DEL}
All Species	0.296	0.066	0.206-0.422	31		
Spiny Dogfish	0.361	0.207	0.169-0.818	16	2	4
Summer Flounder	0.496	0.575	0.278-1.209	5	2	1
Alewife	0.569	0.235	0.338-0.959	8	5	4
Silver Hake	0.132	0.034	0.080-0.185	15	1	8
Atlantic Herring	0.333	0.180	0.170-0.709	8	5	8
Long Horn Sculpin	0.263	0.086	0.125-0.406	16		3
Witch Flounder	0.255	0.064	0.148-0.351	9		3
Red Hake	0.187	0.082	0.088-0.340	18	3	5
Winter Skate	0.320	0.159	0.147-0.595	12	3	7
Little Skate	0.286	0.205	0.074-0.655	15		4
Goosefish	0.086	0.052	0.026-0.179	4	1	11

Scales of Spatial Heterogeneity

Typically, paired tow experiments are conducted with the vessels operating simultaneously along parallel tracks at a specified safe minimum operating distance apart [usually on the order of 0.25-0.5 n mi (~ 460-930 m)]. The intent is to minimize the effects of small-scale spatial heterogeneity on catches to permit the assumption that the two vessels are sampling from the same underlying distribution, simplifying the estimators to be employed in developing the conversion coefficients (Pelletier 1998). Under these assumptions, the effects of small scale heterogeneity in distribution patterns are captured in the residual error structure of the estimation model. Emerging evidence suggests that the assumption of a common underlying distribution may not hold, depending on the tow separation distances and the patchiness in distribution of the species, and alternative estimators may be required (e.g. Cadigan et al. 2006).

To provide initial insights into the relevant de-correlation scales for catches at increasing distances, we examined results from a randomized block experiment conducted during October 28-November 6, 2002 in three areas on Georges Bank and the Gulf of Maine. The use of this experimental data permits examination of covariance patterns at relatively fine spatial scales relative to standard survey data. The experiment was designed to examine effects of variation in trawl warp offsets on gear performance using the *Albatross* towing the Yankee No. 36 trawl (Almeida 2003). Sampling regions and the experimental blocking design are depicted in Figure 1. Each block was 5 n mi x 5 n mi (9.26 km x 9.26 km) and was divided into sub-blocks 1 n mi (1.85 km) on a side. Each sub-block was further subdivided into 4 units. Sampling within each area was conducted by randomly choosing up to 16 sub-blocks (maximum number of blocks to be sampled during a 24 h period). The starting point of the tow within a sub-block was chosen by randomly selecting one of the four units within the sub-block; the tow was then made starting at the midpoint of the chosen unit.

One of the gear configurations was randomly chosen at the start of sampling within each area and sub-blocks were sampled throughout a 24 h period. Following completion of the 24 h sampling period, the gear was switched to the alternative configuration and each sub-block was revisited in the order of the original sampling with an approximate one hour offset to account for tidal changes in the intervening time period.

We examined patterns of spatial coherence for selected species in each of the three sampling areas for both the control and experimental warp treatments separately using geostatistical methods (Rivoirard et al. 2000). For illustration, we fit a spherical model to the observed catch data for two species within each area accounting for anisotropy. In contrast to the isotropic case where the distance at which the autocovariance function declines to zero (the range) is independent of orientation, for the anisotropic model, the range differs with direction. We can define the minor range as the distance at which the sill is reached along the minor axis of the best fitting anisotropic model. The major range is defined as the distance at which the sill is attained along the major axis. We are interested in the estimate of the minor range as an approximate indicator of the maximum distance apart the vessels should operate in paired tow experiments in each area for the species examined. The species in each region were selected on the basis of their numerical abundance. Although the results for individual species varied, the results indicate that in general, distances between the tow tracks of the vessels no greater than 500 m are desirable if disturbance effects can be shown to be small (Table 2).

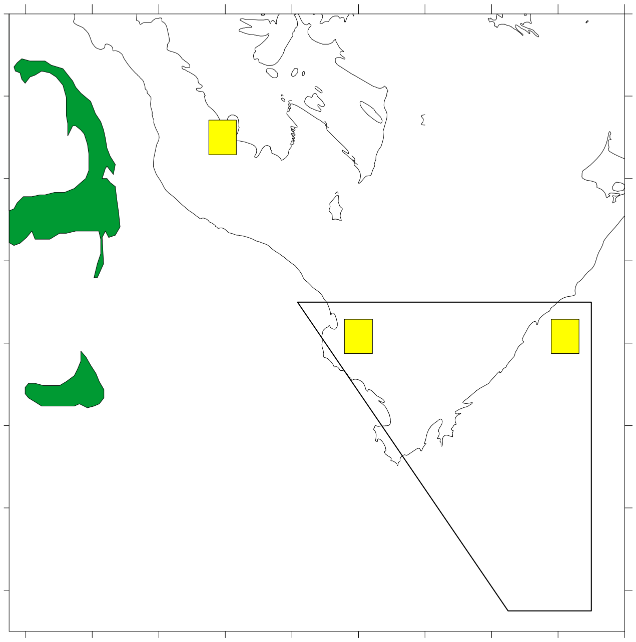

Figure 1. Location of sampling areas in NEFSC trawl warp experiments Oct. 28-Nov. 6 2002. Each yellow square represents the location of an individual sampling block. The open polygon shows the location of fishery Closed Area I.

Table 2. Estimates of the major and minor range for selected species, direction of best rotation for anisotropic models and partial sill for three regions in the Gulf of Maine and on Georges Bank. The direction is the orientation resulting in the best fitting anisotropic model.

Region	Treatment	Species	Major Range	Minor Range	Direction
1	Control	redfish	2481.18	603.87	87.3
1	Treatment	redfish	4788.45	656.91	65.5
1	Control	haddock	8880.18	3451.70	330.9
1	Treatment	haddock	4877.53	1368.54	358.8
2	Control	Atl. herring	1976.42	583.43	321.3
2	Treatment	Atl. herring	1976.42	511.68	344.0
2	Control	Amer. plaice	1976.42	476.36	279.1
2	Treatment	Amer. plaice	1976.42	394.31	337.6
3	Control	red hake	2963.32	652.09	315.2
3	Treatment	red hake	2919.22	455.43	20.9
3	Control	silver hake	2963.32	1291.08	315.9
3	Treatment	silver hake	2837.92	2837.92	9.0

Bigelow Calibration Experimental Design

We propose to implement a two phase design comprising (1) a set of 'whole survey' experiments in which the *Bigelow* will shadow the *Albatross* in the course of standard spring and autumn surveys during 2007-2008, and (2) a series of site-specific experiments at selected locations chosen for high species diversity and biomass levels throughout the survey domain. These experiments will be preceded by a pilot study to specifically examine the question of potential disturbance effects between vessels during the paired tow experiments. The proposed allocation of experiment types based on projected ship schedules for 2007-2008 is provided in Table 3. Barring operational problems and if the proposed schedule can be maintained, it is estimated that on the order of 1380-1480 paired tows between *Albatross* and *Bigelow* can potentially be accomplished. This will then represent one of the most extensive calibration studies of its type conducted to date.

We view the combined strategy of whole survey and geographically restricted experimental designs to be critical. The former will ensure that the full range of habitat/substrate types, depth ranges, and ecological community compositions throughout the standard survey domain will be represented. The site specific experiments provide the opportunity for efficient operation in designated critical areas with transit times between stations kept to a minimum. In addition, our ability to test for factors such as day-night differences in relative catchability while minimizing the effect of confounding factors will be greater in the site-specific surveys.

Table 3. Proposed allocation of vessel calibration studies classified as whole survey shadow experiments and site-specific experiments during 2007-2008.

Tentative Dates	Experiment Type	Expected Days at Sea	Expected Number of Paired Tows
September 2007	Pilot Study	10	60-75*
September-October 2007	Whole Survey	47	270-280
November 2007	Site-Specific	19	180-200
February 2008	Site-Specific	19	180-200
March-April 2008	Whole Survey	47	270-280
May 2008	Site-Specific	19	180-200
September-October 2008	Whole Survey	47	270-280
* Total number of tows by Albatross (not pairs)			

The experiments are designed to test the combined effect of vessel, gear configuration, and sampling protocols under the existing survey program against the proposed set of changes. No attempt will be made to separate the individual effects of vessel, gear, and survey protocols in these experiments.

Differences in vessel (displacement, horsepower, sound) characteristics between the *Bigelow* and *Albatross* are substantial (Table 4) and important differences in the proposed sampling gear (net, doors, sweep type; see Table 5) will also be implemented. These differences collectively will potentially result in large-scale effects on catches of the two vessel/gear combinations. In addition, changes in survey protocols for tow speed and duration will involve a reduction in the mean distance covered during a standard survey tow from approximately 1.9 n mi (3.5 km) to 1.0 n mi (1.85 km). Every attempt will be made to acquire gear performance metrics including bottom contact during the calibration exercise to allow appropriate corrections.

Table 4. Comparison of vessel characteristics of *Albatross*, *Delaware* and *Bigelow*.

Vessel Characteristics	ALBATROSS IV	DELAWARE II	HENRY B. BIGELOW
Length (m)	57	47.4	63.6
Width (m)	9.8	9.1	15
Draft (m)	5.1	5	6.0 (centerboard retracted)
Displacement (metric tons)	987.9	687.6	2,479
Shaft Horsepower; max	1,130	1,230	3,016
Drive	Direct	Direct	Indirect
No. Main Engines	2 diesel	1 diesel	2 electric motors powered by up to 3 diesel generators
Propeller Type	Variable Pitch	Fixed Pitch	Highly Skewed Fixed Pitch
Rudder Type	Kort Nozzle	Standard	Becker High-lift
ICES Radiated Noise Compliant	No	No	Yes
Trawling Towing Point	Rotating Gantry	Fixed Gallows	Fixed Gallows
Distance (m) Between Tow Points	Approx 3	4.9	Approx. 11.3

Table 5. Comparison of gear characteristics of the Yankee No. 36 and four-seam trawls

Gear Characteristic	Yankee No. 36 (Albatross)	Four-seam (Bigelow)
Wingspread (m)	12-13	12-14
Doorspread (m)	25-28	30-35
Headrope Height (m)	1.9-2.0	4.5-5.5
Codend Linear Mesh	3/8” Octagon	1” Diamond
Door type	Polyvalent	Patriot
Bridle Angle (degrees)	22-28	14-15
Sweep	Roller	Rockhopper*

**The Trawl Advisory Panel has expressed interest in comparisons involving the use of a cookie sweep on soft substrate areas for the four-seam net. We explore some of the implications of using two sweeps in the overall survey area in Appendix 1. We propose initially to focus on experiments using the rockhopper sweep alone in our experiments. After the experiments using the rockhopper gear have been completed and adequate conversion coefficients developed, we will turn to testing the effect of using cookie gear.*

Potential effects of disturbance by one vessel on the catch of the other must be considered in these experiments. Previous paired tow experiments have implicitly assumed that there is no effect of one vessel on the catch of the other. The sound and gear characteristics of *Albatross* and *Bigelow* differ markedly as noted above, potentially affecting fish behavior in relation to the vessels. Existing information on fish behavioral response to survey vessels towing trawl gear clearly indicates the potential for changes in the vertical and horizontal distribution of fish in the vicinity of the vessel (e.g. Ona and Godo 1990; Mitson and Knudson 2003; Handegard et al. 2003) with important implications for abundance estimation. Handegard and Tjostheim (2005) reported that gadoids in a fjord in Norway did not react to vessel sound *per se* but did initiate diving behavior when the vessel slowed to set the gear (possibly reacting to low frequency sound when the doors hit the bottom). In the course of the tow, fish swam toward the vessel. Fish in the path of the net were herded by the door plume and ground cables. In contrast, Ono and Godo (1990) reported dispersal away from the vessel and gear. It is not clear if the differences in the sampling environment (fjord vs. open sea), vessel characteristics, or experimental and observational methods accounted for this difference. In general, information on the scale of possible lateral displacement and avoidance is not available to judge appropriate separation distances during the paired tow experiments. Ono and Godo (1990) do report, however, that vertical fish distribution returned to the previous condition 6-7 minutes after the passage of the trawl.

We anticipate that a spatial offset of approximately 500 m should be sufficient to minimize any disturbance effects based on observations of horizontal displacements in experiments in Norway (Handegard and Tjostheim (2005)). However, we will examine evidence for disturbance in a pilot study utilizing the *Albatross* (see below). Experiments designed to estimate disturbance effects and vessel calibration coefficients have been developed by Lewy et al. (2004; see Appendix 2) which could be used in this context. However, we will maintain a 'safe' offset distance that will not require separate estimation of a disturbance term.

Pilot Study

The pilot study will be carried out in fishery Closed Areas throughout the region to maximize the expected catch levels and species diversity (see Figure 2). The study will be conducted by the *Albatross*; the *Bigelow* is not available for paired tows during the survey time period.

We will establish grids in the Hudson Canyon Closed Area, Nantucket Lightship Closed Area, Closed Areas I and II on Georges Bank, and the Western Gulf of Maine Closure Area within which to conduct the experiment. Coverage in these areas will allow representation of a broad spectrum of habitat types and species compositions. A twenty minute bottom trawl will be conducted at the first station. The vessel will return to the start location and repeat the tow with offsets of either 250 m or 500 m (the offset distance of 250 or 500 m for the second tow will be randomly selected). A third tow at the location will be taken but offset by either 250 or 500 m depending on the distance offset randomly selected for the second tow. This sequence will be repeated in each of the remaining four randomly selected locations in the grid. The objective of having observations at 250 m (below our tentative threshold distance) is to see if we can detect disturbance effects below the threshold. The first location will be in the Hudson Canyon Closed Area. The vessel will then transit to Nantucket Shoals Closed Area and the process repeated.

Sampling will then progress to Closed Areas I and II, and the Western Gulf of Maine in this order if time permits.

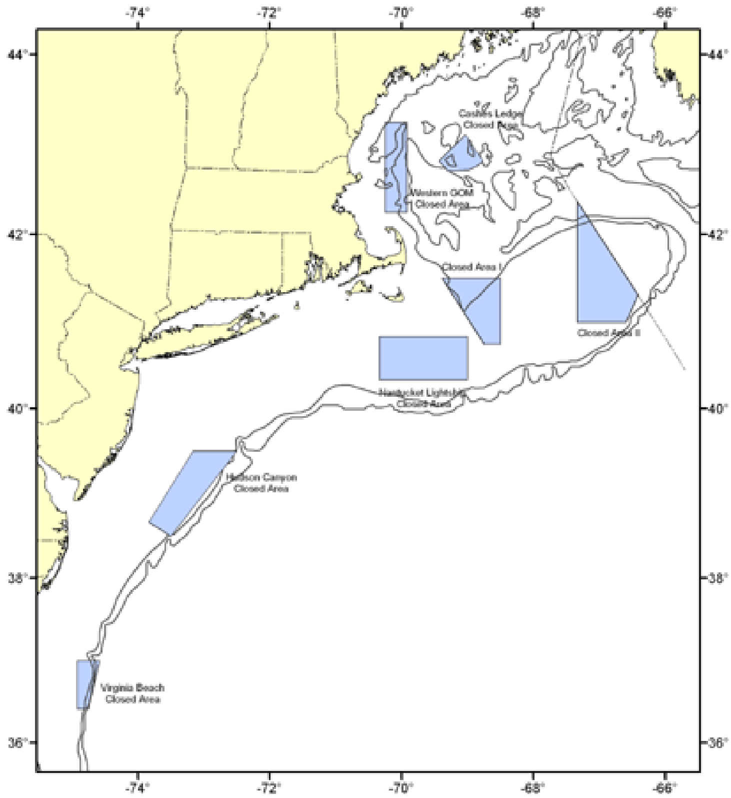

Figure 2. Location of fishery Closed Areas on the northeast continental shelf (blue polygons). The site specific experiments will be placed within the borders of the closed areas.

It is anticipated that five stations (fifteen total tows comprising the control site and two offset locations) can be occupied during a twenty-four hour period in each of the five designated closed areas

An attempt will be made to analyze the pilot experiment results before initiation of the first whole survey experiment. However, because of the short interlude between the completion of the pilot cruise and the start of the first whole survey experiment, it may not be possible to fully analyze the results. In this case, we will tow 500 m apart in this survey and use the first site specific study to conduct further tests of potential disturbance effects.

Whole Survey Experiments

The *Bigelow* and *Albatross* will make paired tows at locations selected for standardized bottom trawl surveys as indicated above. The *Albatross* will proceed to the selected station and execute a standard survey tow. The *Bigelow* will tow a parallel track from the same starting location offset by 500 m unless indications from the pilot study suggest the presence of disturbance effects at this offset. In this case, the offset will be increased to 750-1000 m. Care will be taken to ensure that the tow depths remain comparable between *Albatross* and *Bigelow*. The *Bigelow* start location at each station occupied by *Albatross* will be randomly selected from a small cluster centered on the *Albatross* start location at the specified offset. Preliminary sample locations chosen for the first of the shadow survey experiments under the standard stratified random design are depicted in Figure 3. We note that the *Bigelow* will not operate in water depths less than 60 ft (18.2 m) and therefore some nearshore stations occupied by *Albatross* will not be covered by the *Bigelow* during the shadow survey.

It is conceivable that the *Bigelow* could begin some comparisons between the rockhopper and cookie sweeps while *Albatross* is engaged in nearshore sampling and this option will be explored and logistical considerations evaluated.

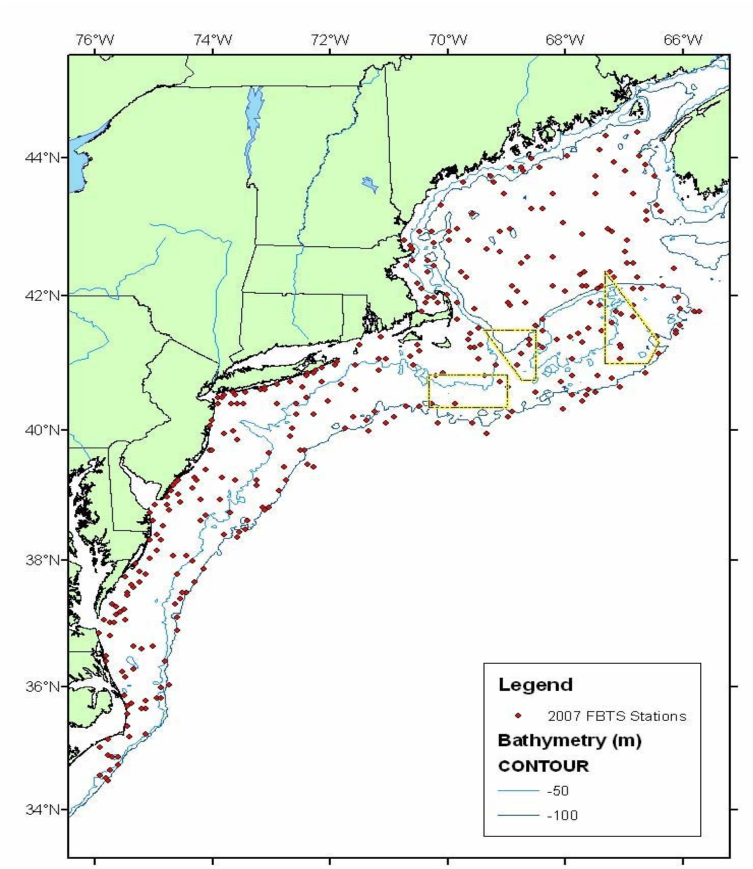

Figure 3. Example distribution of station locations to be sampled during the fall 2007 bottom trawl survey.

We will estimate species and length-specific vessel conversion coefficients using the ratio estimator described above for our preliminary observations and using the approach of Cadigan et al. (2006). We will examine both fixed effects and random effects models using Cadigan's approach. The differences between the fixed effects and random effects models can best be seen by deriving the two models. Let C_{ilb} be the number of fish of a given species caught at station *i* of length *l* by boat *b*, where *b*=A denotes the *Albatross* and *b*=B denotes the *Bigelow*. The instantaneous probability that a fish is captured is denoted $q_{l,b}$ because it is the same for all sites but possibly different for each length and vessel. This can be easily modified to include bottom type or some other factor related to area fished, but is not addressed here. Following the general approach outlined earlier, define the relative efficiency of the *Bigelow* to the *Albatross* as:

$$\gamma_l = \frac{q_{lA}}{q_{lB}}.$$

In the fixed effects model, the fish density encountered by the two vessels is assumed to be the same; that is, $\lambda_{ilA} = \lambda_{ilB} = \lambda_{il}$ for all lengths l. If the capture of each fish is an independent event, then a Poisson distribution, with mean equal to variance, can be used to describe the expected catch by the *Bigelow*:

$$E(C_{ilB}) = q_{lB}\lambda_{il} = \mu_{ilB}.$$

Similarly, the catch by the *Albatross* can be described as a Poisson distribution with expected catch:

$$E(C_{ilA}) = q_{lA}\lambda_{il} = \gamma_l \mu_{ilB}.$$

Although the γ_l's can be estimated directly using a generalized linear model (GLM), a better approach is to use the conditional distribution of the catch by the *Albatross* at a station given the total catch by both vessels at that station. Let c_{il} be the observed total catch by both vessels at station i and length l. The conditional distribution of C_{ilA} given $C_{il} = c_{il}$ follows the binomial distribution where $p_l = \gamma_l/(1+\gamma_l)$ is the probability a captured fish is taken by the *Albatross*:

$$\Pr(C_{ilA} = x \mid C_{il} = c_{il}) = \binom{c_{il}}{x} p_l^x (1-p_l)^{c_{il}-x},$$

This eliminates the need to estimate the mean catch at each station, and thus many nuisance parameters required in the direct GLM approach. The only unknown parameters remaining are the p_l's. To further simplify the model, assume that the relative efficiency (γ_l) varies smoothly over length. Since these values must be non-negative, and typically follow a monotonic function, the common parametric model is $\gamma_l = \exp(\beta_0 + \beta_1 l)$, which leads to the standard logistic regression model:

$$p_l = \frac{\exp(\beta_0 + \beta_1 l)}{1 + \exp(\beta_0 + \beta_1 l)}$$

which is linearized and solved using a GLM in the form

$$\log\left(\frac{p_{il}}{1 - p_{il}}\right) = \beta_0 + \beta_1 l.$$

This model can be extended to include higher order polynomial terms to account for more complex length-specific catchability patterns if necessary. In the random effects model, the relative fish densities for each boat are not assumed equal. Let $\delta_{il} = \log(\lambda_{ilA}/\lambda_{ilB})$ denote the log of the ratio in fish densities for the two boats at station i for length l. The random effects model simply adds this term to the estimating equation so that the proportion of catch at a station by the *Albatross* is:

$$\log\left(\frac{p_{il}}{1-p_{il}}\right) = \beta_0 + \beta_1 l + \delta_{il}.$$

It is easily seen that if the local densities of fish are exactly the same for each vessel at a station, the random effects will be zero. This approach requires the estimation of many additional quasi-parameters compared to the fixed effects model, specifically the sum of observed lengths over all stations, although estimates of the conversion factor are found by integrating over these quasi-parameters using just their estimated variance. One way to reduce the number of parameters estimated is to assume that the δ's at a station are autocorrelated over lengths; that is, the expected mean of the δ's is zero and the variance is an estimated parameter, but $Corr(\delta_{i,j}, \delta_{i,k}) = \varphi^{|j-k|}$ for lengths j and k at station i. This is an AR(1) correlation structure with φ autocorrelation. The δ's are uncorrelated between stations. This random effects model requires a generalized linear mixed model (GLMM) to estimate the parameters, such as the SAS/STAT PROC GLIMMIX or the R lme4 software. These models require an iterative solution that stops when a numerical tolerance for change in the estimates is achieved. Thus, these models require more user input than the fixed effects models.

Cadigan et al. (2006) applied both fixed and random effects models to data collected by two Canadian research vessels. They found the fixed effects model results produced many statistically significant conversion factors between the vessels over a number of species, which were not apparent from examining the raw data. In contrast, the random effects model results produced few statistically significant conversion factors, which appeared to be more consistent with the raw data. The diagnostics for the two approaches favored the random effects model. The random effects results had larger confidence intervals about the conversion factors than the fixed effect results, as expected due to the inclusion of an additional source of variability in the random effects model.

Some preliminary work by Cadigan et al. (2006) suggested the random effects model was less influenced by large outliers (high catch by one vessel but not the other) than the fixed effects model; however, they recommended more study on this topic. The paper also presented techniques for dealing with standardization of tow lengths and sub-sampling of catches. These were found to be of relatively minor importance in their study, but could be applied to the *Bigelow* calibration.

The data used by Cadigan et al. (2006) had small differences in catchability between the two vessels. The *Bigelow* is expected to have a higher catchability than the *Albatross*, perhaps greater than five-fold for some species (see above). The ability to account for the fact that fish densities at a station will be different for the two boats argues for the use of a random effects model, as recommended by Cadigan et al. (2006). The increased confidence intervals about the estimated conversion factors when using random effects models could prove problematic for stock assessments, but probably are more reflective of the actual level of uncertainty. It is hoped that the expected number of stations to be completed will reduce these confidence intervals to a level that is meaningful for stock assessment and ecosystem monitoring.

We will test for the statistical significance of the species/length specific conversion coefficients and examine model diagnostics. We will further determine the mean square error of estimates with and without the conversion coefficient and examine the decision rule of von

Szalay and Brown (2001) specifying that conversion coefficients be applied only when a reduction in the mean square error is effected for the corrected vs. uncorrected estimates.

Site-Specific Experiments

We will conduct the site-specific experiments in fishery Closed Areas from Cape Hatteras to the Gulf of Maine (Figure 2) and/or locations chosen on the basis of recent survey results for high abundance and species diversity. The first site specific experiments will focus on closed areas and/or ancillary sites in the Gulf of Maine and Georges Bank. Three grid locations will be randomly placed in each fishery Closed Area. If the pilot study provides indications of disturbance effects at 500 m, the first site-specific experiment will be devoted to augmenting the information from the pilot study by specifically testing for distance effects following the design specified above and conducted in the each of the closed areas in the Gulf of Maine and Georges Bank region. In this instance we will add offsets of 750 and 1000 m to the experimental design. The principal difference with the pilot study will be that this experiment will involve paired tows between the *Bigelow* and *Albatross* rather than just repeat tows by *Albatross*.

If there are no indications of disturbance effects at 500 m, the first site-specific study will be devoted specifically to augmenting the data base for developing conversion coefficients. It is anticipated that twelve to sixteen paired tows can be conducted in a twenty-four hour period. A sampling grid will be established and sixteen blocks will be randomly chosen. The *Albatross* will initiate its tow from the chosen unit and the *Bigelow* will tow at a 500 m offset distance again following the small cluster design used in the whole survey experiments. Following the completion of twelve to sixteen paired tows in a twenty-four hour period, the next grid will be occupied following the same procedures. Up to five blocks will be occupied in each of the three geographical areas; the number of blocks that can be occupied will depend on consideration of overall transit time and unpredictable factors such as weather conditions. The estimator for the conversion coefficient will follow Cadigan et al. (2006). We will calculate the conversion coefficients using both fixed effects and random effects models and determine which is most appropriate for the experimental data. We will then compare the Cadigan estimator with the results using a ratio estimator as described above.

The second site specific experiment will focus on the Mid-Atlantic region, again with the objective of estimating conversion coefficients. The third site-specific study will be devoted to refining estimates of the conversion coefficient if required and/or testing for differences in the rockhopper vs. cookie sweep. The experiments in the latter case will involve only the *Bigelow* in a randomized complete block design in at least three of the fishery Closed Areas.

Summary

We will develop vessel calibration coefficients to convert *Bigelow* catches to equivalent *Albatross* units using a two phase design comprising (1) a set of three 'whole survey' experiments in which the *Bigelow* will shadow the *Albatross* in the course of standard spring and autumn surveys during 2007-2008, and (2) a three site-specific experiments at selected locations chosen for high species diversity and biomass levels throughout the survey domain. The fundamental design will involve paired tow experiments in which the vessels will operate a 'safe' distant apart to minimize disturbance effects between the vessels. These experiments will be preceded by a pilot study to specifically examine whether the selected spatial offset distance of one half kilometer apart is in fact sufficient to minimize potential disturbance effects between vessels during the paired tow experiments. If questions remain, we will devote the first site specific experiment to further resolution of this issue. Barring operational problems and if the proposed schedule can be maintained, it is estimated that on the order of 810-840 paired tows between *Albatross* and *Bigelow* can potentially be accomplished in the shadow survey experiments and between 540 and 600 paired tows can be completed in the site-specific studies. This will then represent one of the most extensive calibration studies of its type conducted to date.

The design will involve testing the combined effect of vessel, gear, and sampling protocol changes. No attempt will be made to measure the effects of these components individually. Preliminary observations using the four-seam net towed by the *Delaware* in comparison with the Yankee No. 36 trawl towed by the *Albatross* indicate potentially large differences in catches. Much larger catches were obtained with the four-seam net. It is expected that the performance of this net on the *Bigelow* will also result in large differences with the 'standard' Yankee No. 36 net towed by *Albatross*.

A critical issue for analysis following completion of the calibration studies will entail devising the most effective means of combining information from the shadow surveys and the site-specific studies. We will first compare the estimated conversion coefficients derived in each whole survey and test for statistically significant difference among surveys for species and length-specific coefficients. We will repeat this process for the site specific studies as appropriate. (Note that if each of the three site specific studies is devoted exclusively to calibration studies, this will be possible.) If one or more site-specific studies are devoted to other objectives (determining safe offset distances, cookie vs. rockhopper sweeps etc.), not all the information will be suitable for this purpose. If no significant differences are found, the data from the individual paired tow experiments can be directly combined to provide more precise estimates. If differences are found, it will be necessary to determine if these are due to seasonal differences and other factors that should be consistently applied in converting *Bigelow* to *Albatross* catches.

Although the initial focus will remain on converting *Bigelow* to *Albatross* catches, it is recognized that ultimately it will be desirable to establish *Bigelow* catches as the standard as the length of *Bigelow* time series increases. The proposed design and estimators for the conversion coefficient will easily accommodate this change.

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Appendix I. Potential Effects of Two Sweeps on Precision of Predicted Albatross Catch

The use of two different sweeps has been proposed as a way of improving the overall efficiency of capture in the new survey. Trawl surveys conducted in hard bottom areas require large rollers or "rockhoppers" to prevent snags and accumulation of rocks and debris which could damage the net. Rockhoppers are thought to be less efficient at capturing fish in close proximity to the bottom (e.g., flounders). Thus the "cost" of avoiding gear damage in hard bottoms is a reduced probability of capture given encounter for some species. Capture probabilities can be improved in soft bottom areas by using smaller rollers or "cookies" on the sweep because concerns about potential gear damage are reduced.

The implications of using two sweeps on future *Bigelow* trawl surveys are important not only for the calibration experiment but also for the predicted "*Albatross* Equivalents" that would be obtained in future surveys. The number of comparative tows in the calibration experiment will be reduced because two treatment effects must now be estimated from the same number of total tows. One consequence of this reduction is an increase in the variance of the conversion coefficients. The precision of the conversion coefficients are expected to vary by species owing to their differing utilization of hard and soft bottom areas. Another complication of the use of two sweeps is that a full factorial experiment cannot be conducted to compare the rockhopper and cookie sweeps in hard and soft bottoms. Since cookie sweeps cannot be used in hard bottom areas, the differences in gear efficiencies are confounded with differences in distributions of species across these habitats.

The potential effect of a single vs. two sweeps on predicted survey values can be explored by considering the joint effects of variability in estimation in relative abundance and conversion coefficients. If two random variables X and Y are uncorrelated, elementary statistical theory can be used to define the variance of their product V(XY) as $E(X)^2V(Y)+ E(Y)^2V(X)+ V(X)V(Y)$. Let C_B represent some future estimate of an average catch per tow by the *Bigelow* over some sampling domain. The predicted equivalent catch that would have been obtained if the *Albatross* had conducted the survey (i.e., $\hat{C}_A$) can be defined as the product of the calibration coefficient γ and C_B.

$$\hat{C}_A = \gamma C_B$$
$$V(\hat{C}_A) = V(\gamma C_B) = \gamma^2 V(C_B) + C_B^2 V(\gamma) + V(C_B)V(\gamma)$$

Thus the precision of the calibration coefficient and the survey by the *Bigelow* contribute to the precision of predicted value of *Albatross* equivalent. The relative precision of the estimate can be defined as

$$CV(\hat{C}_A) = \frac{\sqrt{\gamma^2 V(C_B) + C_B^2 V(\gamma) + V(C_B)V(\gamma)}}{\gamma \mathbf{C_B}}$$

If two sweeps rather than one are used, the relative precision of the *Albatross* equivalent becomes a function of four random variables rather than two with a corresponding increase in the complexity of the estimate. Let {r} and {c} respectively denote the sets of sample strata where rockhopper and cookie gear can be used. The overall mean catch of the *Bigelow* is estimated as

$$C_B = (1 - p_{\{c\}})C_{B\{r\}} + p_{\{c\}}C_{B\{c\}}$$

where $p_{\{c\}}$ is the proportion of the strata in which the cookie gear can be used. The predicted *Albatross* equivalent catch must now account for two calibration coefficients, say γ_r and γ_c, for rockhopper and cookie sweep effects, respectively. The predicted *Albatross* equivalent catch per tow for two sweeps can now be estimated as

$$\hat{C}_{A(2)} = \gamma_r (1 - p_{\{c\}})C_{B\{r\}} + \gamma_c p_{\{c\}}C_{B\{c\}}$$

Assuming that all of the terms in the above equation are uncorrelated and that the p{c} fractions can be treated as constants, the variance the predicted *Albatross* equivalent is given by

$$\begin{aligned} V(\hat{C}_{A(2)}) &= V(\gamma_r p_{\{r\}}C_{B\{r\}} + \gamma_c p_{\{c\}}C_{B\{c\}}) \\ &= \gamma_r^2 p_{\{r\}}^2 V(C_{B\{r\}}) + p_{\{r\}}^2 C_{B\{r\}}^2 V(\gamma_r) + p_{\{r\}}^2 V(C_{B\{r\}})V(\gamma_r) + \\ &\quad \gamma_c^2 p_{\{c\}}^2 V(C_{B\{c\}}) + C_{B\{c\}}^2 p_{\{c\}}^2 V(\gamma_c) + p_{\{c\}}^2 V(C_{B\{c\}})V(\gamma_c) \end{aligned}$$

where $p_{\{r\}}=(1-p_{\{c\}})$The relative precision of the *Albatross* equivalent estimate immediately follows:

$$CV(\hat{C}_{A(2)}) = \frac{\sqrt{V(\hat{C}_{A(2)})}}{\gamma_r p_{\{r\}}C_{B\{r\}} + \gamma_c p_{\{c\}}C_{B\{c\}}}$$

In general one would expect this CV to be greater than the CV for the case of one sweep as defined above. It is not possible to test this hypothesis explicitly but the general nature of the differences can be explored by applying the method to a particular species from the NEFSC trawl data.

Scenarios

To test this hypothesis, the expressions for the CV for the case of one and two sweeps were applied to spiny dogfish survey data collected by the *Albatross* during autumn (1963-2006) and spring (1968-2006) surveys. The survey strata were partitioned into roller and cookie sets based on a criterion that reduces the number of stocks that would require a so-called split estimate with two calibration coefficients. The following text table illustrates the strata sets used:

Sweep Type	Offshore Strata	Inshore Strata
Roller	13-49	46-92
Cookie	1-12, 61-76	1-45

In the spring, spiny dogfish are found primarily in southern strata where cookie gear would be used. In the summer and autumn, spiny dogfish are more abundant in northern strata where roller gear would be deployed.

For the purpose of this scenario, it was assumed that the historical observations from the *Albatross* were converted to another gear using calibration coefficients that convert the observations to a less efficient gear. This mimics the expected values of the *Bigelow* which, when converted to *Albatross* equivalents, will have calibration coefficients less than one. An example of hypothetical conversion coefficients are provided below:

Conversion	Mean	CV	SD	Var
Cookie	0.2	0.4	0.08	0.0064
Roller	0.4	0.4	0.16	0.0256
Tot(Roller only)	0.3	0.2	0.06	0.0036

It is assumed that the cookie gear is 5 (i.e. 1/0.2) times as efficient as the existing gear and that the new roller gear is 2.5 (i.e., 1/0.4) times as efficient as the existing gear. The CVs on each of these gears is 0.4. The calibration coefficient for the roller only scenario is 0.3, implying about a 3-fold increase in the efficiency of the roller gear when used in all areas. The calibration coefficient is assumed to represent a mixture of the 0.2 and 0.4 conversion coefficients. Moreover, it is assumed that the precision of this estimate would be higher because more comparative tows could be used in its estimation.

Results

The relationship between the mean and standard deviation by stratum is illustrated in Figure A.1.1. Both surveys suggest a high degree of overdispersion wherein the variance increases faster than the mean and the coefficient of variation appears to be relatively constant. The estimates of zero standard deviations in both plots represent strata where only one tow was taken.

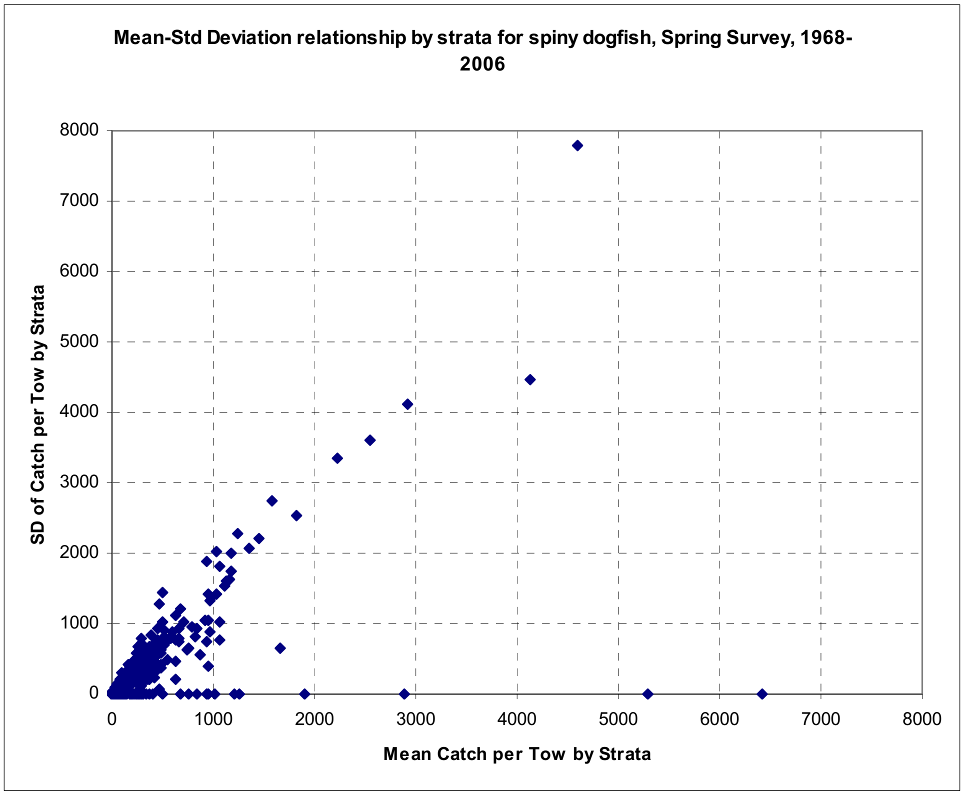
Owing to the differences in the seasonal distribution of spiny dogfish, the relative importance of the catch rates in the cookie and roller strata varies by season. Spiny dogfish are more abundant in the mid-Atlantic during the spring (Fig. A.1.2). In the autumn, spiny dogfish are more abundant in strata where the proposed cookie gear could not be used. It is interesting to note the changes in relative importance of the stratum sets between seasons. Such variability would be expected in other species that migrate north and south along the shelf.

The season variations between stratum sets have implications for the coefficients of variation in mean abundance (Fig. A.1.3). In the spring, when most of the population is in the cookie strata, the coefficient of variation for all strata is similar to the CV for the cookie gear (Fig. A.1.3 top). Conversely, in the autumn when spiny dogfish have a more northerly distribution in the roller gear stratum, the overall CV more closely matches the CV for the roller gear. The CV of total catch in the spring has consistently been about 20%. The CV for the autumn survey averages slightly higher and exhibits greater inter-annual fluctuations.

The joint effects of variation in relative precision of the catch rates and the calibration coefficients are summarized in Fig. A.1.4. Equations for the coefficient of variation for one and two sweeps were applied to the realized time series of spiny dogfish catch rates for the spring and autumn surveys. The relative variability increases compared to the original observations. This of course, simply reflects the contribution of the variability of the calibration coefficients. When a single calibration coefficient (CV(tot), Fig. A.1.4) is applied, the CV increases to about 30% in both surveys. As before, the autumn survey values exhibit greater inter-annual variability. When two conversion coefficients are used, the relative variability increases to about 40% for both surveys (Fig. A.1.4).

The scenario provides some insights into the potential effects of using two sweeps but it lacks realism in several important ways. First, the *Albatross* has always used a roller type of sweep so the catch rates and their variability only reflect seasonal migration patterns rather than different gears. It would be expected that catch rates would be higher in the “cookie strata” when the *Bigelow* is used. Second, it is assumed that the *Albatross* tows are converted to a hypothetical gear with lower efficiency. This preserves the expected direction of change when the *Bigelow* is converted to *Albatross* units, but ignores the expected increase in average catch rates when the *Bigelow* is used. Third, this approach assumes that the relative variability of *Bigelow* catches will be the same as those demonstrated by the *Albatross*. Variances increase much more rapidly than the means, suggesting that a negative binomial model is appropriate for describing the underlying pattern of spiny dogfish distribution. This property is expected to apply to other species but the overdispersion may lower for less abundant or more demersal species. Finally, the illustration for spiny dogfish is probably not representative for other species whose migrations may not be as extensive or for those species, like summer flounder, whose distributions may have a much greater fraction in one of the stratum sets (i.e. roller vs. cookie). For summer flounder, most of the population is expected to be concentrated in the “cookie strata.” The relative variability for catches in the “roller strata” would be expected to be greater since these strata would have fewer total samples.

Additional analyses of other species may be instructive. More realistic values for the means and variances of conversion coefficients would also allow greater insights into the magnitude of the expected increase in the calibration-adjusted survey.



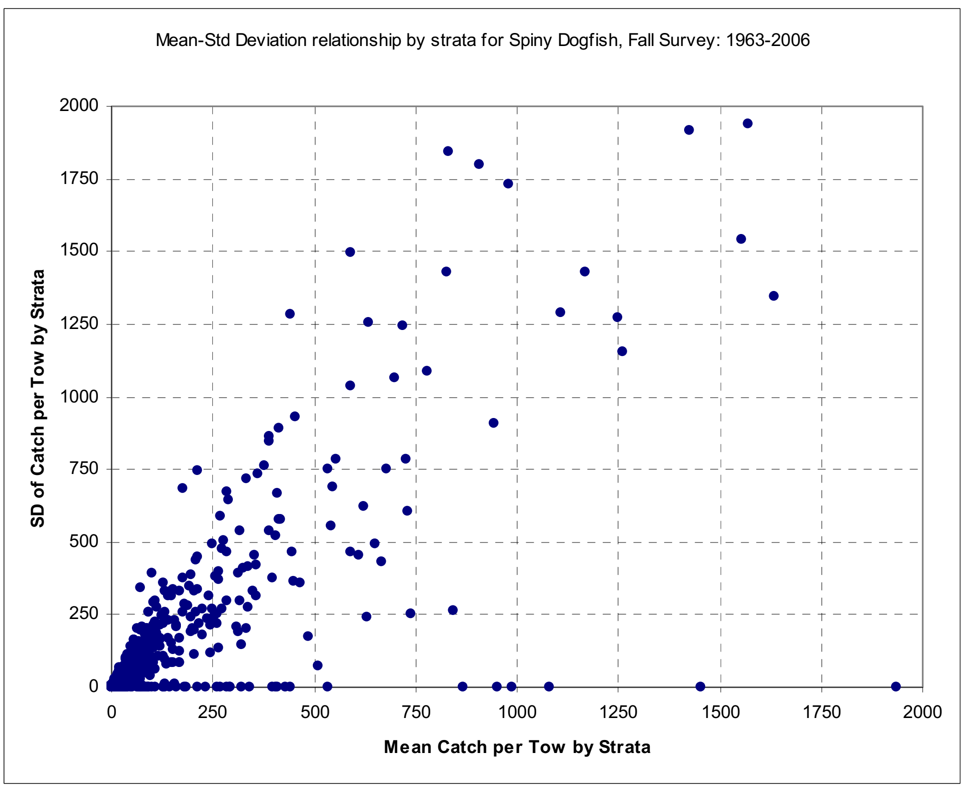
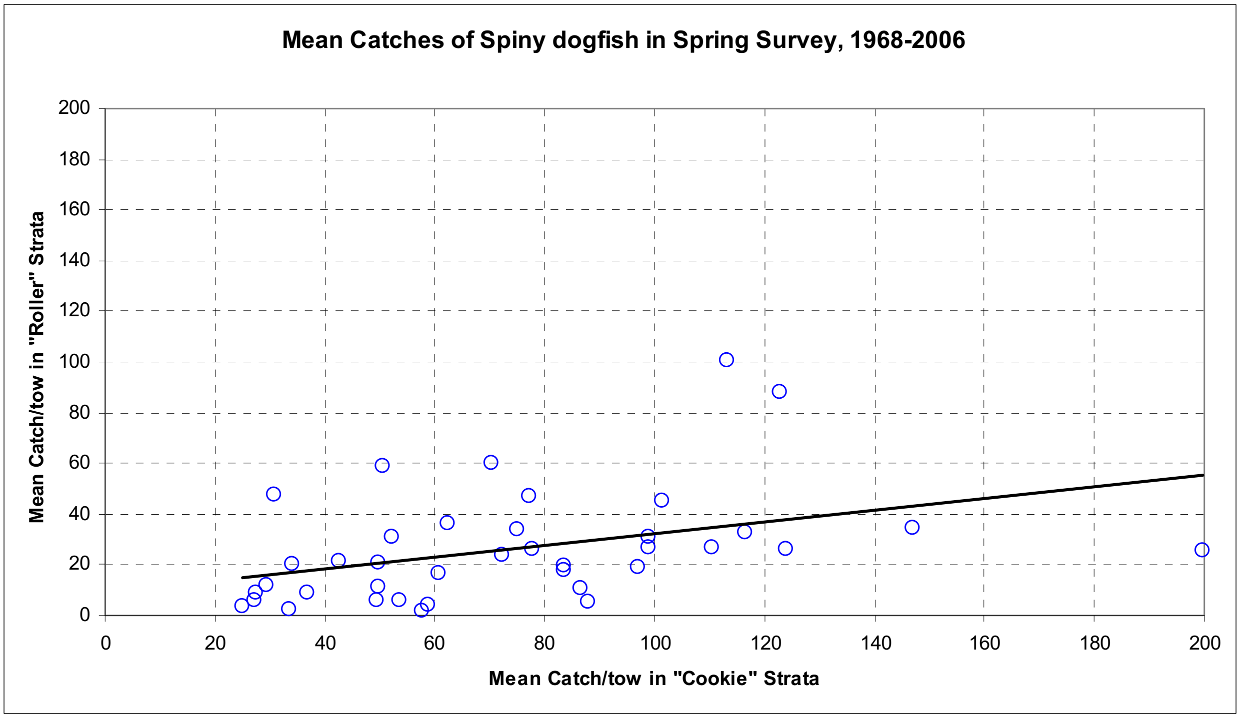


Figure A.1.1. Comparison of standard deviation vs. mean catch per tow by stratum for spiny dogfish in the NEFSC spring survey, 1968-2006 (top) and fall survey, 1963-2006 (bottom). Each point represents a stratum mean and standard deviation.



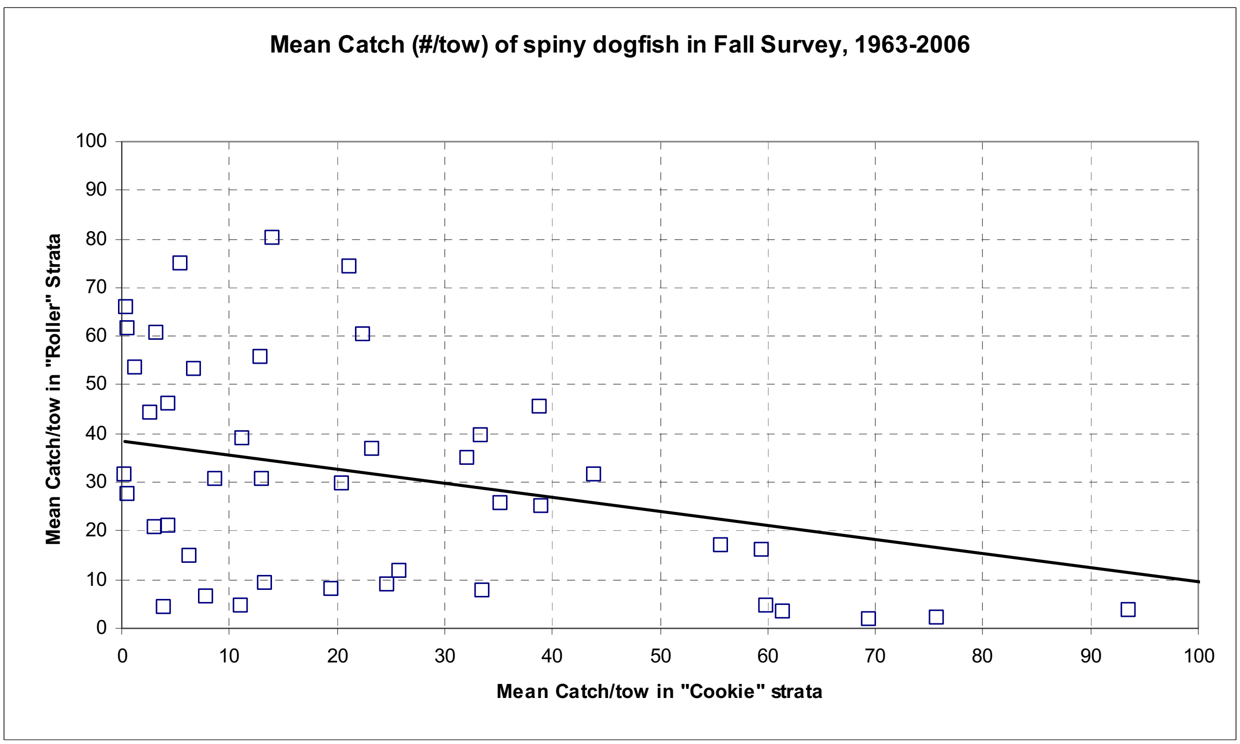
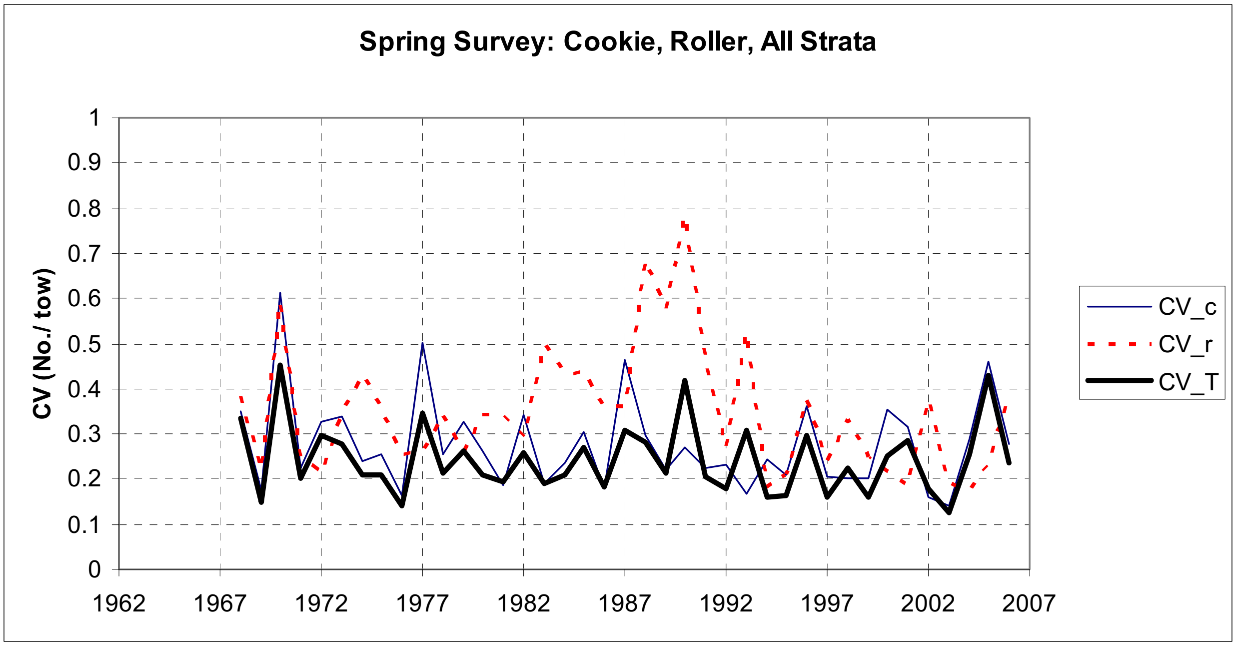


Figure A.1.2. Comparison of annual means for "cookie" and "roller" strata sets by year for the NEFSC spring (top) and fall (bottom) trawl surveys for spiny dogfish. Each point represents an annual value. The regression lines are used to highlight the differing relationships between seasons.



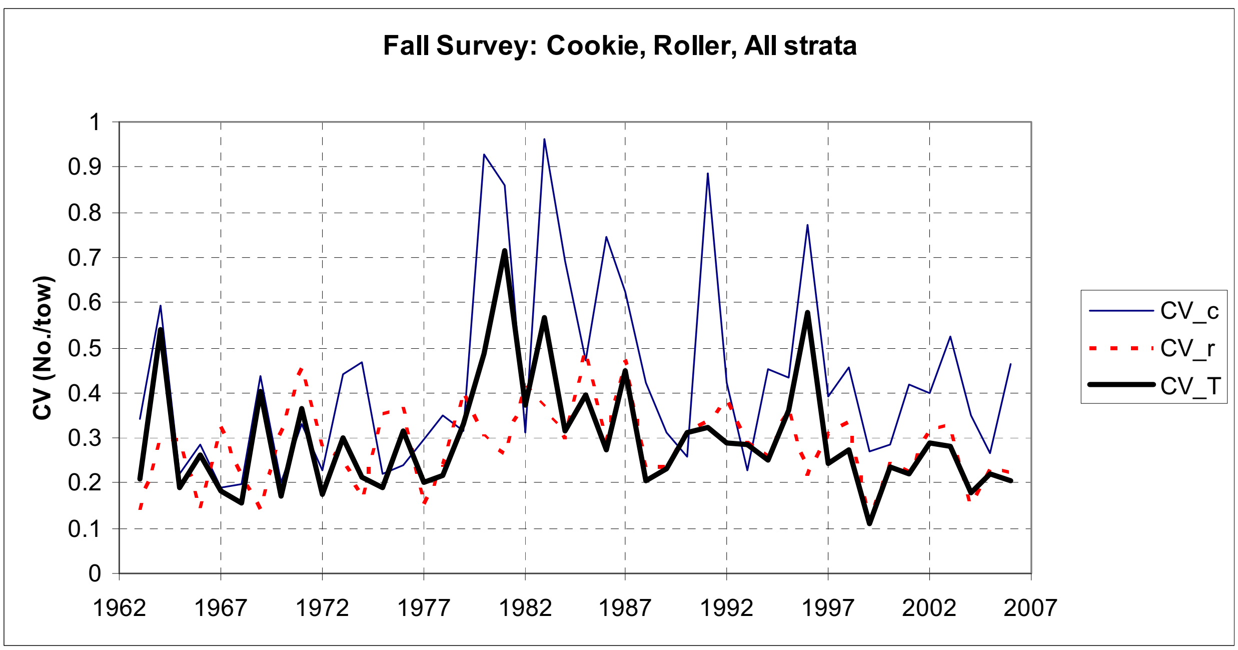
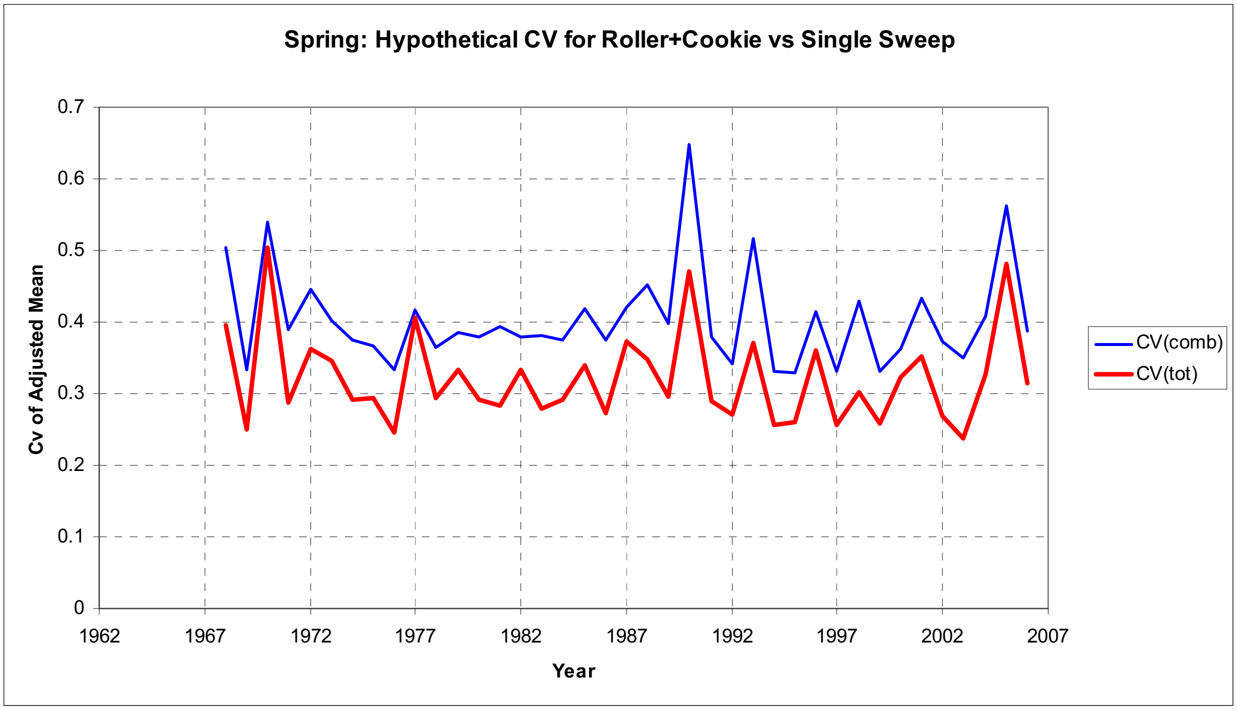


Figure A.1.3. Relative precision of catch per tow (numbers) for the NEFSC spring (top) and fall (bottom) trawl survey indices for spiny dogfish. Coefficients of variation (CV) were computed for the "cookie strata" (CV_c), the "roller strata" (CV_r) and all strata (CV_T) by year.



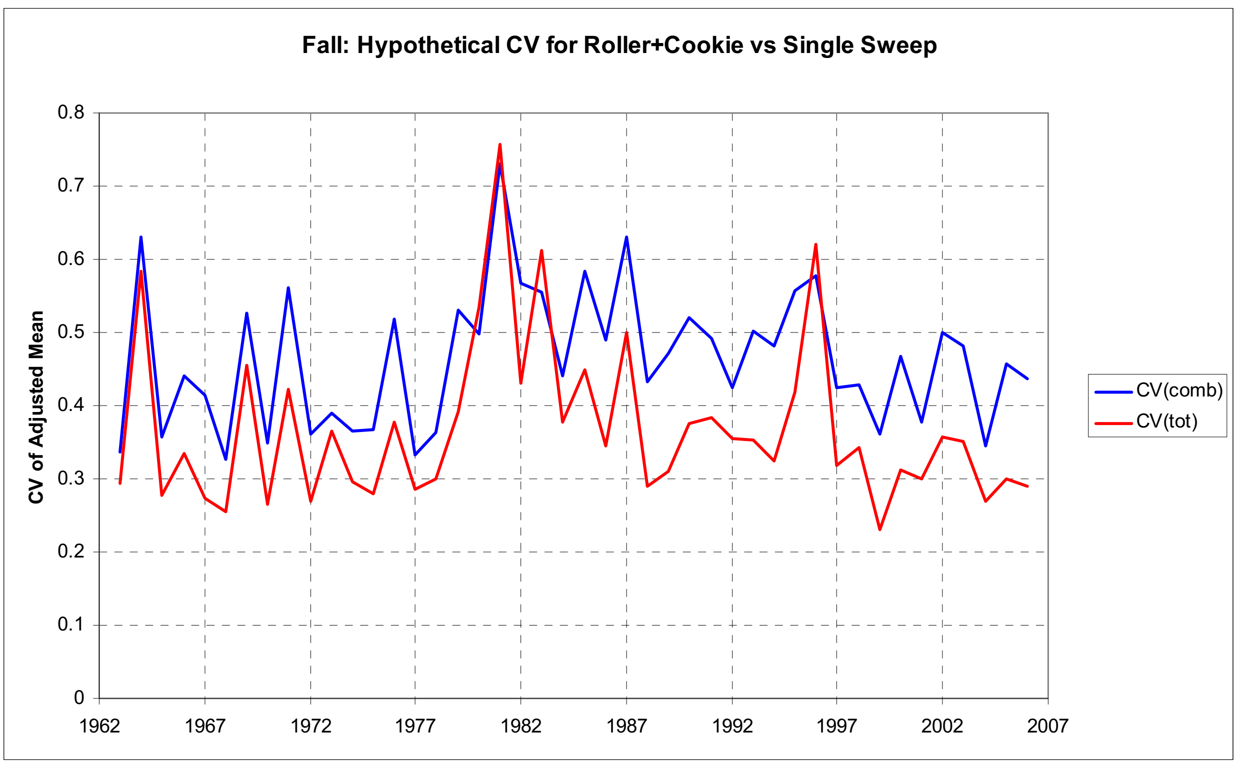


Figure A.1.4. Comparison of coefficients of variation for the calibration scenarios described in the text. *Albatross* means for NEFSC spring (top) and fall (bottom) surveys are converted to new indices based on CV(tot) and CV(comb). CV(tot) assumes one gear conversion; CV(comb) assumes two gears. See text and text table for assumed calibration values.

Appendix 2. Estimation of Disturbance Effects

An approach for inter-vessel standardization involving the joint estimation of vessel calibration coefficients and disturbance factors was proposed by Lewy et al. (2004). Although we do not propose to employ the Lewy et al. design, an outline of the procedure is provided below to illustrate how direct estimates of vessel interference effects can be developed. The experimental design employed by Lewy et al. entails a strategy in which the vessels sequentially operate on the same tow path for each paired tow. Occupying the same track line is intended to minimize the effect of small-scale patchiness in distribution on expected catches. However, it requires that the disturbance effect of the first vessel to occupy the trawl path on the expected catch of the second vessel be estimated. In order to estimate both the disturbance effect and the relative efficiencies of the two vessels, Lewy et al. define four possible tow sequence types: (1) the 'standard' vessel (here designated vessel A) is towed twice in sequence along the same track, (2) a tow of the standard is followed by a tow of the second vessel (designated vessel B), (3) a tow by the new configuration is followed by the standard and (4) the new configuration is applied twice in sequence. At a minimum, at least one of the vessels must undertake repeat tows and one of the sequence combinations involving the new and standard vessel/gear configurations must be represented (using either combinations of sequence type 1 and 2 or sequence types 3 and 4).

When the catches (in numbers) of a given species/size class in each tow of a sequence are independent Poisson random variables (as assumed by Lewy et al. 2004), the catch in either the first or second tow conditional on the total catch of both tows is a binomial random variable. For sequence type 1, the unconditional means (and variances) of the first and second tows at station i are $E(C_{11,i,l}) = q_{l,A}\lambda_{i,l}$ and $E(C_{12,i,l}) = q_{l,A}\alpha_l\lambda_{i,l}$ where $q_{l,A}$ is the catchability of vessel A for size class l, $\lambda_{l,i}$ is the density of individuals of size class l prior to the first tow and α_l is the disturbance effect of vessel A on the density of size class l, which can be either less than or greater than one. For sequence type 2, the unconditional means (and variances) of the first and second tows at station i are $E(C_{21,i,l}) = q_{l,A}\lambda_{i,l}$ and $E(C_{22,i.l}) = q_{l,B}\alpha_l\lambda_{i,l}$ where $q_{l,B}$ is the catchability of the vessel B for size class l.

Note that the catchabilities in these models are assumed to not depend on the density of individuals similar to conventional models for abundance estimation from surveys, but there is a further assumption that the disturbance effect also does not depend on density.

Conditional on the total catch of both tows of sequence type 1 at station I ($C_{1,i,l}$), the catch in the second tow is a binomial random variable with mean $E(C_{12,i,l} \mid C_{1,i,l}) = C_{1,i,l}\, p_{12,i,l}$ and variance

$$Var(C_{12,i,l} \mid C_{1,i,l}) = C_{1,i,l}\, p_{12,i,l}\,(1 - p_{12,i,l}) \quad \text{where:}$$

$$p_{12,i,l} = \frac{E(C_{12,i,l})}{E(C_{11,i,l}) + E(C_{12,i,l})} = \frac{q_{l,A}\alpha_l\lambda_{i,l}}{q_{l,A}\lambda_{i,l} + q_{l,A}\alpha_l\lambda_{i,l}} = \frac{\alpha_l}{1+\alpha_l}$$

For sequence type 2 the conditional catch in the first tow is a binomial random variable with mean $E(C_{21,i,l} \mid C_{2,i,l}) = C_{2,i,l}\, p_{21,i,l}$ and variance $Var(C_{21,i,l} \mid C_{2,i,l}) = C_{2,i,l}\, p_{21,i,l}\,(1 - p_{21,i,l})$ where

$$p_{21,i,l} = \frac{E(C_{21,i,l})}{E(C_{21,i,l}) + E(C_{22,i,l})} = \frac{q_{l,A}\lambda_{i,l}}{q_{l,A}\lambda_{i,l} + q_{l,B}\alpha_l\lambda_{i,l}} = \frac{\gamma_l}{\gamma_l + \alpha_l}$$

and as before the size-specific calibration coefficient γ_l is the ratio of the survey catchability coefficients for vessel A and vessel B. Thus, the conditional probabilities are the same for each station of a sequence type. The relative efficiency, γ_l, and the disturbance effect, α_l, can be parameterized as a generalized linear model. For the binomial family with a logit link function:

$$\log\left(\frac{p_{12,i,l}}{1 - p_{12,i,l}}\right) = \beta_{0,l}$$

and

$$\log\left(\frac{p_{21,i,l}}{1 - p_{21,i,l}}\right) = \beta_{0,l} + \beta_{1,l}$$

and the maximum likelihood estimators for the disturbance and conversion coefficient parameters are:

$$\hat{\alpha}_l = \left(\frac{\hat{p}_{12,i,l}}{1 - \hat{p}_{12,i,l}}\right) = e^{\hat{\beta}_{0,l}}$$

and

$$\hat{\gamma}_l = \left(\frac{\hat{p}_{12,i,l}}{1 - \hat{p}_{12,i,l}}\right)\left(\frac{\hat{p}_{21,i,l}}{1 - \hat{p}_{21,i,l}}\right) = e^{2\hat{\beta}_{0,l} + \hat{\beta}_{1,l}}$$

respectively with approximate variances:

$$Var(\hat{\alpha}_l) = \left(\frac{\alpha_l(\alpha_l + 1)^2}{C_{1,l}}\right)$$

and

$$Var(\hat{\gamma}_l) = \frac{\gamma_l^{\ 2}}{\alpha_l}\left(\frac{(\alpha_l + 1)^2}{C_{1,l}} + \frac{(\gamma_l + \alpha_l)^2}{\gamma_l C_{2,l}}\right)$$

where $C_{1,l}$ and $C_{1,1}$ are the total number of individuals of length class *l* caught in sequence type 1 and sequence type 2 stations.

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The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

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