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Use of commercial vessels in survey augmentation: the size-frequency distribution

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SUMMARY: The trend towards use of commercial vessels to enhance survey data requires assessment of the advantages and limitations of various options for their use. One application is to augment information on size-frequency distributions obtained in multispecies trawl surveys where stratum boundaries and sampling density are not optimal for all species. Analysis focused on ten recreationally and commercially important species: bluefish, butterfish, *Loligo* squid, weakfish, summer flounder, winter flounder, silver hake (whiting), black sea bass, striped bass, and scup (porgy). The commercial vessel took 59 tows in the sampled domain south of Long Island, New York and the survey vessel 18. Black sea bass, *Loligo* squid, and summer flounder demonstrated an onshore-offshore gradient such that smaller fish were caught disproportionately inshore and larger fish offshore. Butterfish, silver hake, and weakfish were characterized by a southwest-northeast gradient such that larger fish were caught disproportionately northeast of the southwestern-most sector. All sizes of scup, striped bass, and bluefish were caught predominately inshore. Winter flounder were caught predominately offshore. The commercial vessel was characterized by an increased frequency of large catches for most species. Consequently, patchiness was assayed to be higher by the commercial vessel in nearly all cases. The size-frequency distribution obtained by the survey vessel for six of the ten species, bluefish, butterfish, *Loligo* squid, summer flounder, weakfish, and silver hake, could not be obtained by chance from the size-frequency distribution obtained by the commercial vessel. The difference in sample density did not significantly influence the size-frequency distribution. Of the six species characterized by significant differences in size-frequency distribution between boats, all but one was patchy at the population level and all had one or more size classes so characterized. Although the variance-to-mean ratio was typically higher for the commercial vessel, five of the six cases that were otherwise were among the species for which the size-frequency distribution differed between the two vessels. Thus, the origin of the significant differences observed between vessels would appear to lie in the spatial pattern of the species as it interacts with the tendency for one vessel to obtain large catches more frequently for some size classes. One consequence of differential distribution and catchability is that more large fish were present in the commercial vessel catches than in the survey vessel catches in cases where the two vessels obtained different size-frequency distributions. Application of commercial vessels to the evaluation of size frequency hinges on understanding how to interpret differences among boats, gear, and sampling design. Here we show that key ingredients to this understanding are the degree of nonlinearity in catchability across a range of size classes, the interaction of varying spatial arrangements among size classes and the sampling design, and the interaction of varying spatial arrangements with differential catchability.

Keywords: fish, survey, catchability, size-frequency distribution, spatial distribution.

RESUMEN: UTILIZACIÓN DE BUQUES COMERCIALES PARA AUMENTAR LA INFORMACIÓN DE CAMPAÑAS DE EVALUACIÓN: LA DISTRIBUCIÓN DE FRECUENCIAS DE TALLAS. – La tendencia hacia la utilización de buques comerciales para incrementar y optimizar los datos de campañas de evaluación requiere la valoración de las ventajas y limitaciones de las distintas opciones para su uso. Una aplicación consiste en aumentar la información referente a distribuciones de frecuencias de tallas obtenidas en campañas de evaluación de pesquerías de arrastre multiespecíficas, en las que los límites de los estratos y la densidad del muestreo no son óptimas para todas las especies. El presente análisis se centró en diez especies importantes, tanto desde el punto de vista recreacional como comercial: *Pomatomus saltatrix*, *Peprilus triacanthus*, *Loligo pealei*, *Cynoscion regalis*, *Paralichthys dentatus*, *Pleuronectes americanus*, *Merluccius bilinearis*, *Centropristis striata*, *Morone saxatilis* y *Stenotomus chrysops*. El buque comercial realizó 59 lances en la zona muestreada al sur de Long Island, Nueva York, y el buque de investigación, 18. *C. striata*, *L. pealei* y *P. dentatus* presentaron un gradiente desde la costa hacia mar abierto tal que los individuos de menor talla fueron capturados desproporcionadamente en aguas costeras y los ejemplares de mayor talla a mayor distancia de la costa. *P. triacanthus*, *M. bilinearis* y *C. regalis* se caracterizaron por un gradiente sudoeste-nordeste tal que los ejemplares de mayor talla se capturaron desproporcionadamente al nordeste del sector más sudoccidental. Todas las tallas de *S.*

chrysops, *M. saxatilis* y *P. saltatrix* fueron capturadas predominantemente en aguas costeras. *P. americanus* se capturó predominantemente en aguas alejadas de la costa. El buque comercial se caracterizó por una mayor frecuencia de grandes capturas para la mayoría de especies. En consecuencia, la agregación en áreas de alta densidad se mostró superior en el buque comercial en casi todos los casos. La distribución de frecuencias de tallas obtenida por el buque de investigación para seis de las diez especies (*P. saltatrix*, *P. triacanthus*, *L. pealei*, *P. dentatus*, *C. regalis* y *M. bilinearis* no pudo ser obtenida por azar a partir de la distribución de frecuencias de tallas obtenida por el buque comercial. La diferencia en densidad del muestreo no influenció significativamente la distribución de frecuencias de tallas. De las seis especies caracterizadas por diferencias significativas en la distribución de frecuencias de tallas entre buques, todas menos una mostraron agregaciones en áreas de alta densidad a nivel poblacional y todas presentaron una o más clases de talla caracterizadas de esta manera. Aunque la relación varianza-media fue típicamente superior para el buque comercial, cinco de los seis casos en que no fue así se dieron entre las especies en las que la distribución de frecuencias de tallas fue distinta entre los dos buques. Así, el origen de las diferencias significativas observadas entre buques radicaría en la pauta espacial de las especies al interaccionar con la tendencia de un buque a obtener grandes capturas con más frecuencia para algunas tallas. Una consecuencia de la distribución diferencial y capturabilidad es que más individuos de gran tamaño estuvieron presentes en las capturas del buque comercial que en las capturas del buque de investigación en casos en los que los dos buques obtuvieron distintas distribuciones de frecuencias de tallas. La utilización de buques comerciales para la evaluación de frecuencias de tallas depende de la comprensión sobre cómo interpretar las diferencias entre buques, artes de muestreo y diseño de muestreo. Mostramos aquí que ingredientes clave para esta comprensión son el grado de no-linearidad en la capturabilidad a lo largo de un rango de clases de talla, la interacción de distribuciones espaciales distintas entre clases de talla y el diseño de muestreo, así como la interacción de distintas distribuciones espaciales con la capturabilidad diferencial.

Palabras clave: peces, campañas de muestreo, capturabilidad, distribución de frecuencias de talla, distribución espacial.

INTRODUCTION

Increasingly sophisticated approaches to fisheries management have increased emphasis on the reliability and adequacy of the principal underlying data, specifically landings, CPUE, and survey indices (e.g. Ricker, 1975; NEFSC, 1988; Schnute, 1985). In the Mid-Atlantic Bight, continental shelf surveys of fish stocks are conducted in the fall, winter, and spring by the National Marine Fisheries Service using trawl gear (NEFSC, 1988; Brodziak and Hendrickson, 1999). These surveys have a stratified random design (e.g. NEFSC, 1988; Dawe and Hendrickson, 1998). The size of the region surveyed and the number of fish stocks requiring survey places limitations on the area surveyed, the number of stations sampled, and the number of gear types that can be used.

One option to resolving issues related to coverage and gear is to augment the survey using commercial vessels (e.g. Otto, 1986; NEFSC, 2000a,b). These vessels typically have a more limited range, are available for a more limited time, and have varying catch efficiencies. Consequently, incorporating such data into the assessment database is not straightforward. Significant issues include the reproducibility of the size-frequency distribution between gear types, the conflation of multiple vessels' databases, and the degree of improvement in survey indices produced by increasing station density or enlarged survey domain, given the increased cost and logistical hurdles imposed. Cooperative survey efforts often target single species (e.g. surf clams, ocean quahogs, monkfish — NEFSC, 2002, 2003), but multispecies survey augmentation programs are also underway (e.g. HSRL, 2003a,b). Multispecies programs are likely to exacerbate these difficulties because optimal sampling design cannot be achieved for many species in either the base survey or the survey augmentation program.

In this study, a survey vessel and a commercial vessel conducted a series of multispecies-targeted tows inshore off Long Island, New York. The survey vessel tows were a subset of the NMFS Fall multispecies survey (e.g. NEFSC, 2001). The goal was to examine the use of commercial vessels to augment trawl-based multispecies stock surveys with particular emphasis on the use of commercial vessels to evaluate the influence of sampling density on the size-frequency distribution and on the degree to which size-frequency data collected by the two vessels can be standardized to a common database.

METHODS

Field data collection

The program was conducted in two phases. Phase I included thirty-seven tows by the trawler *F/V Jason & Danielle* conducted side-by-side the survey vessel during the Spring survey in February and March, 2001. These tows were taken near the edge of the continental shelf from the Maryland/Virginia border to the eastern end of Long Island. Station depths ranged from about 90 to 365 m. An in-depth analysis of Phase I has been reported by Powell *et al*. (in press). Phase II was conducted in September, south of Long Island, New York, in depths <55 m (Fig. 1). The survey vessel conducted

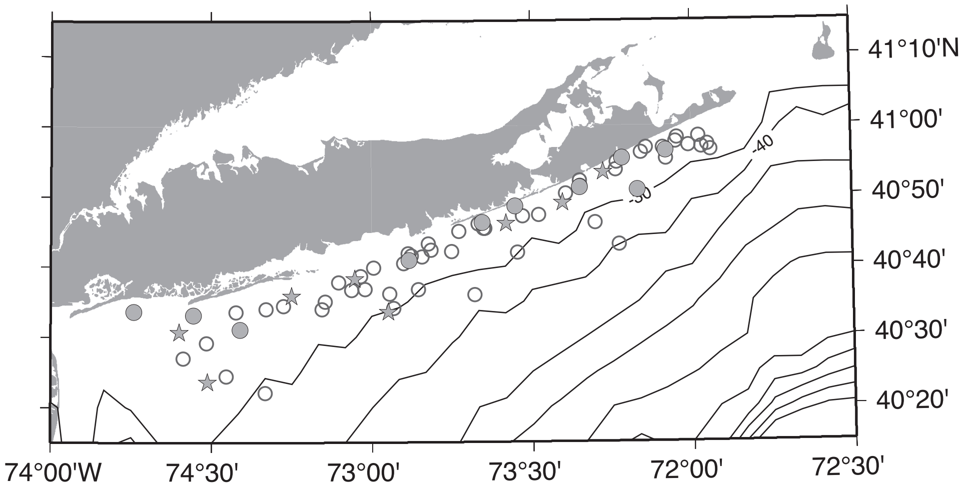

FIG. 1. – Locations of sampling stations in Phase II: (star) side-by-side tows; (fillet circle) additional stations sampled by the survey vessel; (open circle) additional stations sampled by the commercial vessel. Locations of Phase I tows are given in Figure 1 of Powell *et al.* (in press).

18 tows, eight of them side-by-side with the *F/V Jason & Danielle*, as part of the Fall survey (NEFSC, 2001). Concurrently, the commercial vessel conducted an additional 59 tows, approximately tripling the total survey coverage for the region, to determine the influence of increased coverage on survey size-frequency estimates. The present analysis focuses on Phase II.

The Fall survey in the region just south of Long Island is characterized by an offshore gradient in station density across the inner half of the continental shelf (NEFSC, 2001). More stations are taken in the inshore portion of this region than farther offshore. The gradient in station density is a product of the configuration of strata in the stratified random sampling design used in the larger Fall survey, a small portion of which was represented by the domain of the Phase II sampling program. To retain this proportional distribution in station density, random stations were selected for the commercial vessel, but with a similar gradient in station density (Fig. 1). The survey vessel used a #36 bottom survey trawl with a 1.27-cm codend mesh. The commercial vessel used a 20.3-cm 4-seam balloon net with a 6-cm codend. This mesh size is standard for the *Loligo* squid fishery and often used in other small-mesh fisheries. The gears are more completely described in NEFSC (1988) and HSRL (2003a,b). Efficiency of capture for the net used by the commercial vessel declined at sizes less than about 7 cm (see also NEFSC, 2002). For this reason, analyses were limited to size classes ≥7 cm.

Tow times were standardized to 30 min. Tow duration was defined as time on-bottom to time off-bottom. Boat position was logged at 1-minute intervals during the tow by DGPS. Towing speed for the survey vessel was generally somewhat higher than for the commercial vessel. Consequently, total distance traveled by the survey vessel was longer. Tow distance varied from 2.45 km to 3.43 km for the *F/V Jason & Danielle* with the vast majority of tows in the range of 2.7 to 3.1 km. Shorter tows were necessitated by occasional large catches. All data were standardized to 30-min by simple proportion (Pelletier *et al.*, 1998).

Survey vessel tows were much more consistent and did not require *a posteriori* standardization. Tow distance was 3.5 km.

Onboard catch analysis included measurement of catch weight for each species and length measurements for selected species. Mantle length was taken for squid species and total length for finfish species. Whenever catch size permitted, minimally 100 lengths were taken for each target species.

Data analysis

Rago *et al.* (1998) estimate the swept area of a survey vessel tow to be 0.0185 km^2, but do not indicate if this estimate is based on door spread or wing spread. Because net sensor data were unavailable for the commercial vessel at the time of sampling, data analysis focused on proportional comparisons rather than quantitative comparisons. Catchability comparisons, therefore, encompass the effect of differential swept area in addition to variations in gear efficiency. As few commercial vessels have sophisticated net sensors, this constraint represents a typical and

TABLE 1. – The domain-average size-frequency recorded for the *F/V Jason & Danielle* during the Fall survey series for common species, expressed as the percentile sizes and the mean size. Percentiles were based upon the compilation of the area-weighted size frequencies for each tow. Also provided is the mean size obtained from the simple compilation of all samples for the target species. All fish ≤6 cm were excluded from the analysis. Full size-frequency distributions are shown in Figures 2-4.

	Weighted average catch (cm)				Simple average
Species	25th percentile	Median	75th percentile	Mean	Mean
Black sea bass *Centropristis striata*	24.00	28.00	34.00	28.80	28.61
Bluefish *Pomatomus saltatrix*	19.00	28.00	45.00	32.42	31.75
Butterfish *Peprilus triacanthus*	8.00	8.00	9.00	8.40	8.28
Loligo squid *Loligo pealei*	8.00	9.00	11.00	9.67	9.21
Loligo squid (diel-corrected)	8.00	9.00	11.00	9.60	9.16
Scup *Stenotomus chrysops*	8.00	8.00	17.00	12.04	13.21
Silver hake *Merluccius bilinearis*	21.00	22.00	23.00	21.06	20.27
Striped bass *Morone saxatilis*	66.00	70.00	75.00	70.80	69.71
Summer flounder *Paralichthys dentatus*	36.00	40.00	46.00	41.44	41.53
Weakfish *Cynoscion regalis*	20.00	36.00	42.00	31.50	31.50
Winter flounder *Pleuronectes americanus*	22.00	24.00	29.00	25.93	25.65

TABLE 2. – The domain-average size-frequency recorded for the survey vessel during the Fall survey series for common species, expressed as the percentile sizes and the mean size. See Table 1 for further explanation.

	Weighted average catch (cm)				Simple average
Species	25th percentile	Median	75th percentile	Mean	Mean
Black sea bass *Centropristis striata*	25.00	28.00	32.00	29.86	29.83
Bluefish *Pomatomus saltatrix*	11.00	14.00	21.00	19.72	13.86
Butterfish *Peprilus triacanthus*	8.00	9.00	9.00	9.18	10.29
Loligo squid *Loligo pealei*	7.00	8.00	9.00	8.75	8.45
Loligo squid (diel-corrected)	7.00	8.00	9.00	8.56	8.31
Scup *Stenotomus chrysops*	7.00	14.00	17.00	13.15	14.54
Silver hake *Merluccius bilinearis*	8.00	9.00	10.00	9.10	9.04
Striped bass *Morone saxatilis*	70.00	70.00	70.00	70.00	70.00
Summer flounder *Paralichthys dentatus*	36.00	38.00	43.00	40.32	39.79
Weakfish *Cynoscion regalis*	15.00	18.00	38.00	23.67	20.19
Winter flounder *Pleuronectes americanus*	23.00	24.00	28.00	25.86	28.11

expected limitation on the integration of data from the commercial vessel with the Fall survey program. Subsequent measurements by HSRL (2003a,b) show that swept area based on door spread for a typical *F/V Jason & Danielle* 30-min tow is approximately 0.17 km^2, up to 10 times that of the survey vessel, depending on the method of calculation.

Analyses were conducted for selected species of recreational or commercial importance. These species are listed in Tables 1 and 2. For *Loligo* squid, a diel correction factor obtained from NEFSC (2002) was included, where indicated. This correction factor adjusted catches for diel migration that reduces catch efficiency. The correction factor was specified separately for nighttime, dusk, and daytime hours (NEFSC, 2002) and was assumed to be the same for both vessels.

Size-frequency distributions were calculated in two ways. A simple compilation of all tows was computed, weighting each tow equally. However, one objective of the analysis was to evaluate the influence of station distribution and density on size-frequency estimates. Stations were not randomly distributed over the study domain as a consequence of the offshore gradient in station density. Thus, an area-weighted size-frequency distribution was estimated also by assigning a weight (ω_i) to each tow size frequency in proportion to the area represented by each station in the spatial array of stations:

$$\sum_{i=1}^{n} \omega_i \ frequency_i.$$

An unbiased weight was assigned to each station by nesting the stations into a grid of Delaunay triangles (Davis, 1986) using the spatial distribution of stations to identify segment connections (Gold *et al.,* 1977). Thiessen polygons were then erected around each station (McCullagh and Ross, 1980; Davis, 1986) and the ratio of the area of each Thiessen polygon to the total area of the domain used to weight each tow size-frequency distribution.

Species' size frequencies were compared using two groups of metrics. First, the entire size-frequency distribution was described in terms of the 25th, 50th, and 75th percentiles and the mean size. Second, the size-frequency distribution was split into four even categories across the size range from 7 cm to the largest size captured by either vessel in the tow series. These size-class boundaries varied for each species according to the size of the largest captured individual. The individuals captured in each tow were then assigned to these four size classes and the number of individuals per tow in each size class used as the metric.

Statistical analysis

Between-boat comparisons of the descriptors of the area-weighted size frequencies, including the 25th, 50th, and 75th percentiles and the mean size, were carried out using Monte Carlo tests (Noreen, 1989). One-thousand subsamples of the survey or commercial dataset were obtained by choosing stations randomly without replacement. The RAN1 pseudorandom number generator of Knuth described in Press *et al.* (1989) was used. Each of these station subsamples was used to generate a new grid of Delaunay triangles within the domain described by the original dataset. Thiessen polygons were created for each of the triangle grid sets and weights assigned accordingly to each of the stations in the one-thousand data subsets.

Estimating area averages required establishing the boundaries of the sampled domain. Domain boundaries were established by calculating the average of the distances from each tow to its nearest neighbor. The domain was then expanded beyond the outlying tows by this amount. The Thiessen polygon approach, as implemented, generated somewhat different domains with each sample subset because each sample subset varied slightly in its relationship to boundary points imposed to constrain the shape of the domain. Accordingly, we examined the possibility that catch statistics generated from station subsets might be biased by small changes in domain area. Correlation coefficients between domain area and area-weighted size-frequency metrics obtained from 1000 random selections of 15 and 30-tow subsets did not exceed 0.15 for any species, however. Accordingly, this potential bias was not a significant determinant of area-weighted size-frequency distribution.

Comparisons of relative catchability focused on the boat-to-boat ratio of mean catch numbers ($\overline{catch}$) for selected size classes:

$$\frac{\overline{catch}_{survey\ vessel}}{\overline{catch}_{commercial\ vessel}} = \frac{\dfrac{\sum_{i=1}^{n} catch_{i[survey\ vessel]}}{n_{survey\ vessel}}}{\dfrac{\sum_{i=1}^{n} catch_{i[commercial\ vessel]}}{n_{commercial\ vessel}}}$$

The distribution of catch weights among the tows was evaluated using Elliott's D (Elliott, 1977):

$$D = \sqrt{\frac{\sigma^2}{\bar{x}} 2(n-1)} - \sqrt{2(n-1)-1}$$

The distribution of catch weights of the two vessels was compared using the variance-to-mean ratio. The premise is that two sets of samples came from the same distribution if the variance-to-mean ratio is the same for each. The comparison is only valid if the number of samples is the same in both datasets. Thus, comparison required first the resolution of the problem of unequal sample number. To reduce sample number, one-thousand subsamples of the desired (lower) sample number were obtained from the data set having the larger sample number by choosing stations randomly without replacement using the RAN1 pseudorandom number generator. Each of these station subsamples was used to generate a new variance-to-mean ratio and this distribution of variance-to-mean ratios was compared with the variance-to-mean ratio observed for the smaller dataset using a Monte Carlo test (Noreen, 1989).

Null catches are inherently ambiguous because a true zero resulting from the absence of the species or size class in the towed area cannot be discriminated from the detection limit for the species. An independent estimate of the detection limit cannot be made. Null catches, accordingly, diverge from the distribution of other tow values. One option is to assume a distribution of the Poisson-plus-added-zeros type (El-Shaarawi, 1985). The simpler alternative, chosen here, is to exclude null catches from analysis.

Probability of occurrence was tested for significance using the binomial distribution (Conover, 1980).

Geographic distributions were examined using spatial autocorrelation (Cliff and Ord, 1973) with Moran's I and Geary's C as the test statistics, where:

$$I = \left(\frac{n}{W}\right) \frac{\sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{ij} z_i z_j}{\sum_{i=1}^{n} z_i^2};$$

$$C = \left(\frac{n-1}{2W}\right)\frac{\sum_{i=1}^{n}\sum_{\substack{j=1 \\ i\neq j}}^{n} w_{ij}\left(x_i - x_j\right)^2}{\sum_{i=1}^{n} z_i^2};$$

$$W = \sum_{i=1}^{n}\sum_{\substack{j=1 \\ i\neq j}}^{n} w_{ij} z$$

$$z_i = x_i - \bar{x};$$

n = number of samples; x_i = datum of each sample i; and w_{ij} = a weighting measure as described subsequently.

Significance levels were calculated under the assumption of randomization (Jumars *et al.*, 1977).

Moran's I is sensitive to the location of extreme departures from the mean ($x_i - \bar{x}$). The expected value of I for spatially randomly distributed samples is $-(n-1)^{-1}$, a number close to zero at high n (Cliff and Ord, 1973). High values of I occur if x_i and x_j are both much above or much below the mean. Values above $-(n-1)^{-1}$ indicate positive spatial autocorrelation (i.e. tows more similar than expected by chance). Large negative values of I occur when one value is much above and one much below the mean. Values of I below $-(n-1)^{-1}$ indicate negative spatial autocorrelation (i.e. tows less similar than expected by chance). Geary's C is sensitive to sample-to-sample variation ($x_i - x_j$). Values above 1.0 indicate negative spatial autocorrelation, an even distribution. Values below 1.0 indicate positive spatial autocorrelation, a patchy distribution.

Calculation of Moran's I or Geary's C is contingent on the mathematical representation of the spatial relationship of the samples (w_{ij}). We used an inverse distance weighting method (Jumars *et al.*, 1977), where

$$w_{ij} = \frac{max(distance(km)_{ij}) - distance(km)_{ij}}{max(distance(km)_{ij})}$$

Spatial relationship also was examined using directional spatial autocorrelation. In this case, the w_{ij} were assigned based on the angle formed by a segment $\overline{IJ}$ with a preferred direction $\overline{IP}$: $\angle PIJ$. Orientation of segment $\overline{IJ}$ parallel to the preferred direction, $\angle PIJ = 0$ or π, generated $w_{ij} = 1.0$. Orientation of segment $\overline{IJ}$ perpendicular to the preferred direction, $\angle PIJ = \pi/2$, generated $w_{ij} = 0.0$.

The spatial arrangements of tow datasets, size classes a and b for example, were compared using residual analysis. The residual was calculated as:

$$residual(a)_i = observation(a)_i - expected(a)_i$$

where

$$expected(a)_i = $$

$$= \frac{observation(b)_i}{\sum_{i=1}^{n} observation(b)_i} \times \sum_{i=1}^{n} observation(a)_i$$

The residuals were then used as data in spatial autocorrelation analysis with the inverse distance weighting scheme or the directional weighting scheme and significant differences in the two distributional patterns identified by significant autocorrelation of the residuals (Powell *et al.*, 1987a,b).

RESULTS

Catch statistics

Descriptive statistics for the size-frequency distributions of common species are given in Tables 1 and 2 and compared in Figures 2-4. Ten commercially or recreationally significant species were caught commonly enough for analysis.

In rare cases, the survey vessel averaged a larger number of individuals of a certain species and size class per tow than the commercial vessel (Table 3). However, in the vast majority of cases, the ratio of catch means fell below 0.2, indicating that the commercial vessel caught more than five times as many fish as the survey vessel. Swept areas possibly varied by as much as a factor of 10 between the two vessels, so that much of this difference is thereby explained. Ratios of catch means below 0.1 occurred for one or more size classes for black sea bass, silver hake, striped bass, summer flounder, weakfish, and winter flounder (Table 3). Values below 0.2 occurred for at least one of four size classes for all ten target species. No consistent bias appeared to exist with size class. Large and small size classes were just as likely to have low or high relative catchabilities. Catchability was, of course, consistently greater for the survey vessel for sizes <7 cm due to the larger-sized mesh of the codend used on the commercial vessel.

Mean area-weighted size was higher for the commercial vessel in 7 of 10 species, a distribution not different from chance (P = 0.10). The 75th percentile size was larger for the commercial vessel in all eight cases where the percentile size varied, a

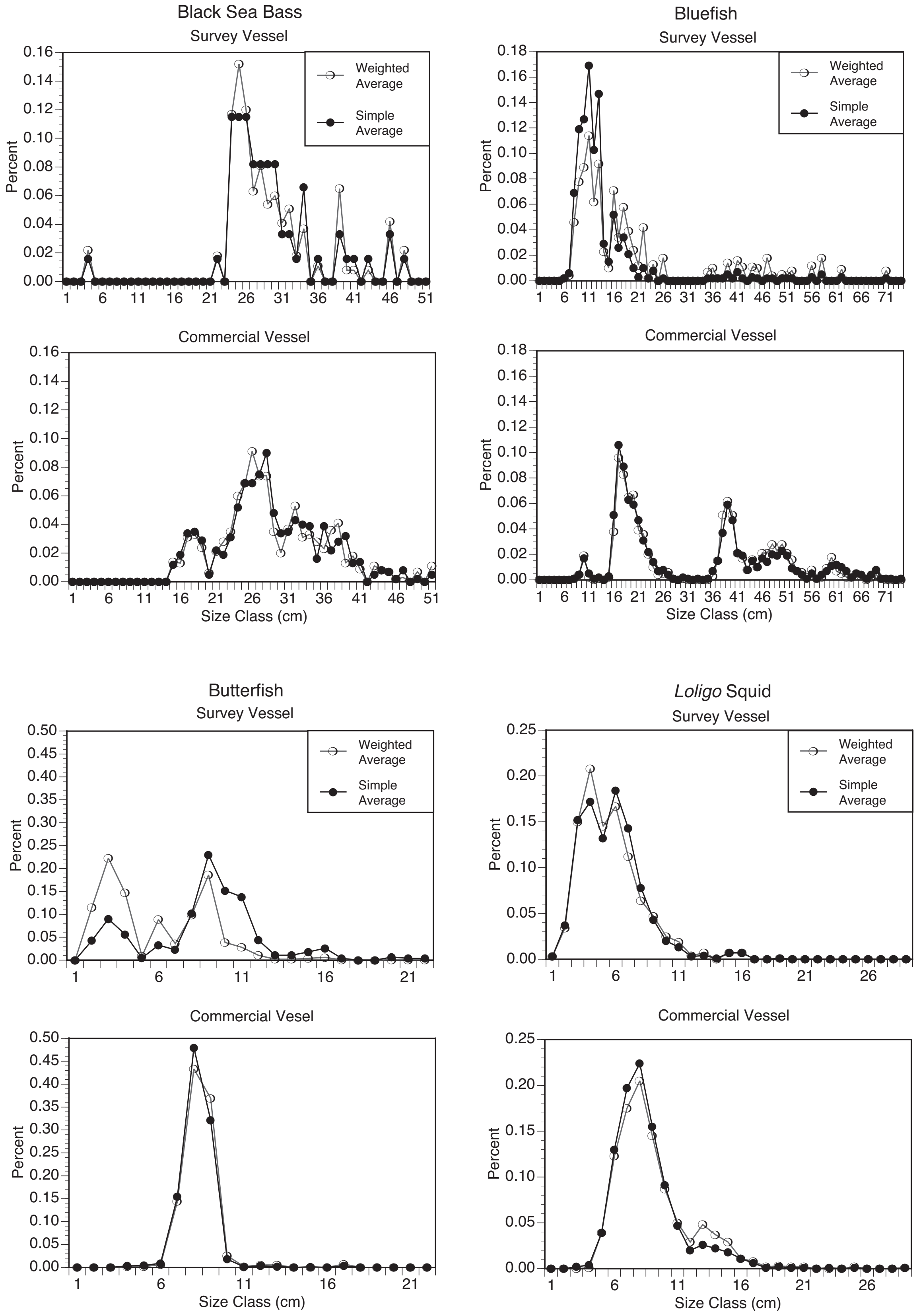

FIG. 2. – Comparison of the domain-weighted size-frequency distribution and the size-frequency distribution obtained by a simple compilation of the data for black sea bass, bluefish, butterfish and *Loligo* squid for the survey vessel and the commercial vessel.

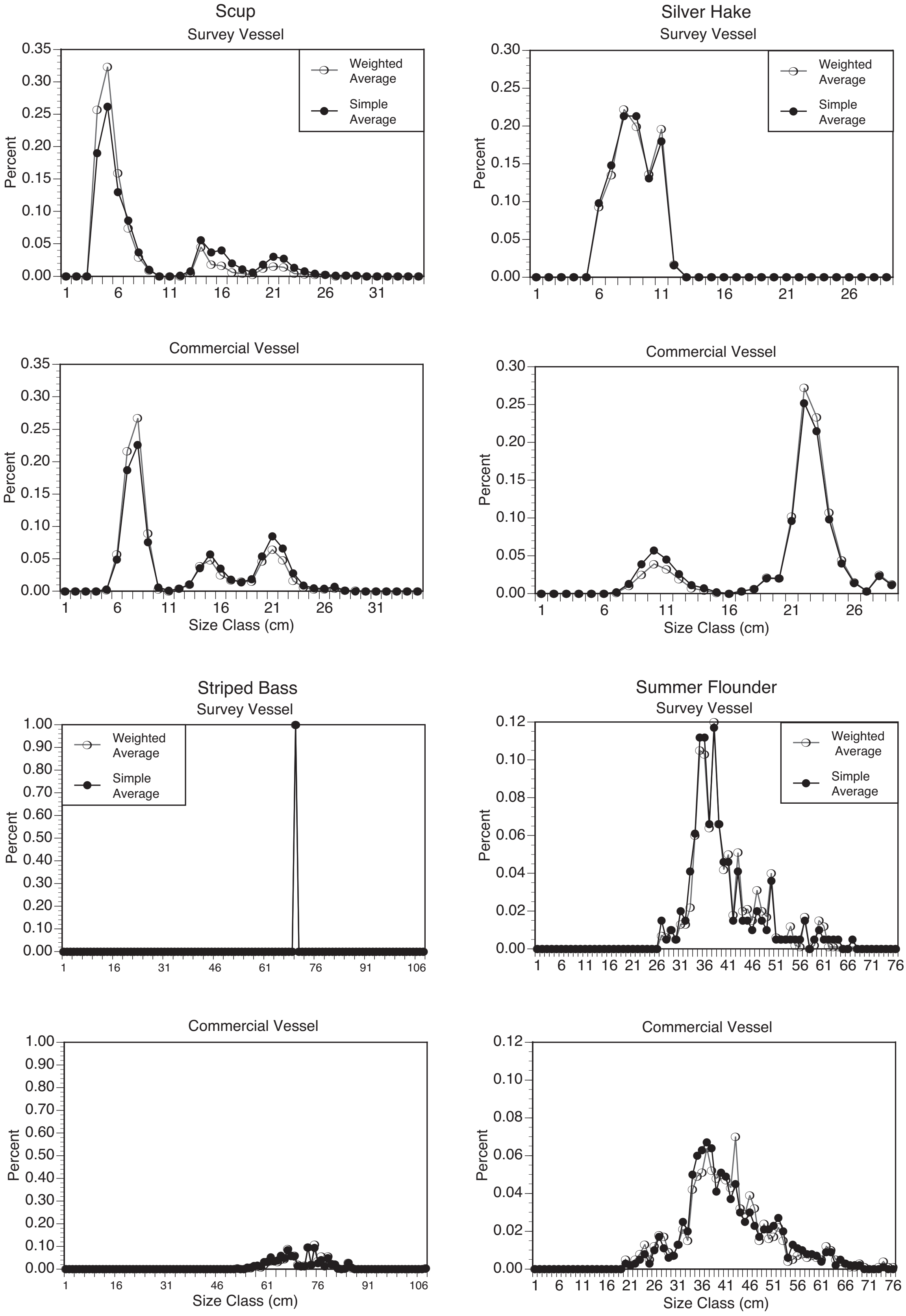

FIG. 3. – Comparison of the domain-weighted size-frequency distribution and the size-frequency distribution obtained by a simple compilation of the data for scup, silver hake, striped bass and summer flounder for the survey vessel and the commercial vessel.

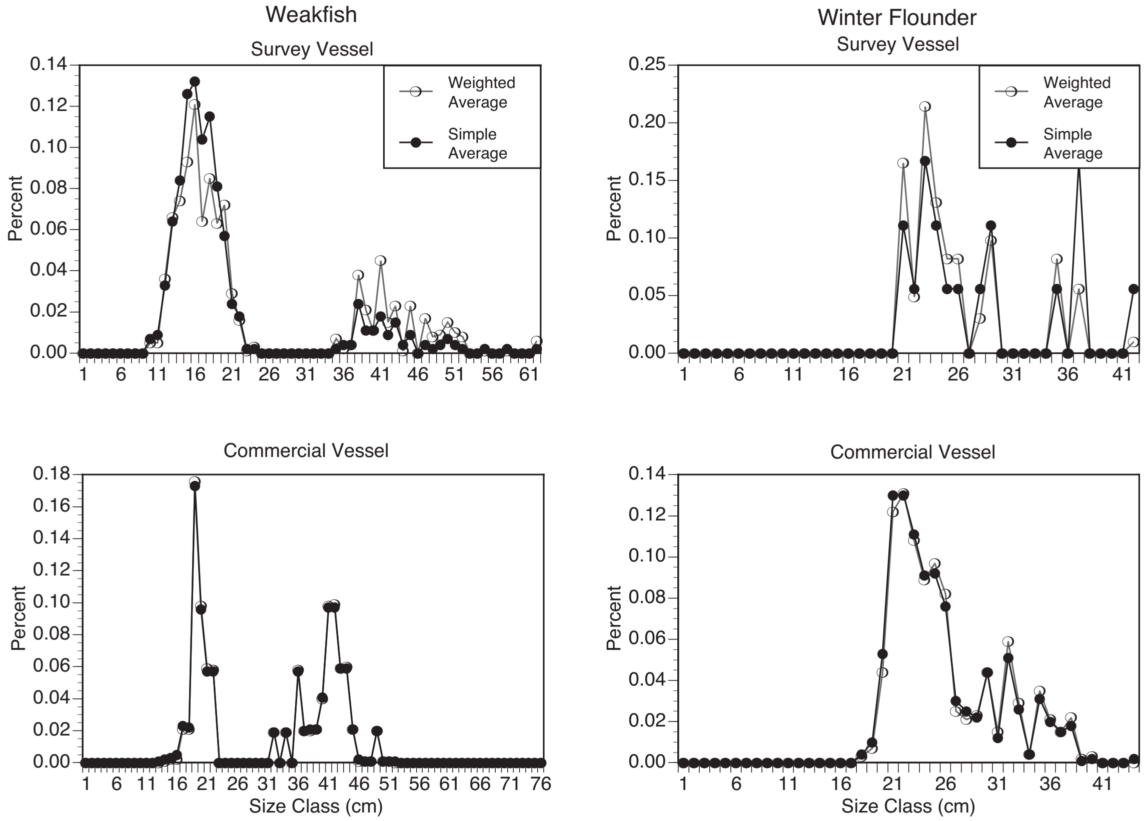

FIG. 4. – Comparison of the domain-weighted size-frequency distribution and the size-frequency distribution obtained by a simple compilation of the data for weakfish and winter flounder for the survey vessel and the commercial vessel.

TABLE 3. – Ratio of mean catches in the commercial and survey vessel tow series for the four size classes defined in Tables 4 and 5, calculated as

$$\frac{\overline{catch}_{survey\ vessel}}{\overline{catch}_{commercial\ vessel}}$$

The calculation used the observed, non-area-weighted catch values. Value of 0.000 indicates a ratio <0.001.

Species	Small	Medium Small	Medium Large	Large
Black sea bass	0.000	0.194	0.140	0.262
Bluefish	3.338	0.181	0.210	0.117
Butterfish	0.143	2.957	1.554	—
Loligo squid	0.299	0.143	0.377	0.116
(diel-corrected)	0.464	0.149	0.475	0.134
Scup	0.279	0.442	0.364	1.979
Silver hake	0.387	0.000	0.000	0.000
Striped bass	—	0.000	0.009	0.000
Summer flounder	0.000	0.379	0.149	0.155
Weakfish	0.091	0.012	0.012	0.249
Winter flounder	—	0.024	0.051	0.221

ratio unexpected by chance (binomial test, P <0.005). The same was true in only 5 of 8 cases for the 25th percentile and 5 of 7 cases for the 50th percentile, ratios not different from chance (P = 0.24, 0.13, respectively). Where a difference existed, the interquartile range was higher in 6 of 8 cases for the commercial vessel, an unlikely outcome by chance (P = 0.076). Thus, on the average, catches by the commercial vessel were characterized by a greater proportion of larger fish and a greater range of the most common sizes.

For bluefish, *Loligo* squid, silver hake, summer flounder, and weakfish, the 25th percentile, 75th percentile, and the mean were higher for the commercial vessel, indicating an upwards shift of the size-frequency distribution (Figs. 2-4). The same trend is present for striped bass, however survey vessel catches were too meager to accurately estimate percentiles (Fig. 3). The commercial vessel had a larger representation of some smaller and some larger size classes for black sea bass (Fig. 2), striped bass (Fig. 3), and summer flounder (Fig. 3) and, consequently, a larger interquartile range. For bluefish (Fig. 2) and weakfish (Fig. 4), the survey vessel tended to catch proportionately more small fish, yet for bluefish, the interquartile range was still larger for the commercial vessel. In most cases, the proportion of fish less than 7 cm was much higher for the survey vessel (e.g. Fig. 2), in keeping with the smaller mesh size used by the survey vessel.

Distribution of species and size classes

The target species fell into one of four geographic patterns: predominately inshore, predominately offshore, distributed in an inshore-offshore gradient, and distributed in a southwest-northeast gradient (Figs. 5-9). The latter two distributions were characterized by size classes that were not equivalently distributed within the domain. In the first case, the smaller fish were inshore and the larger fish off-

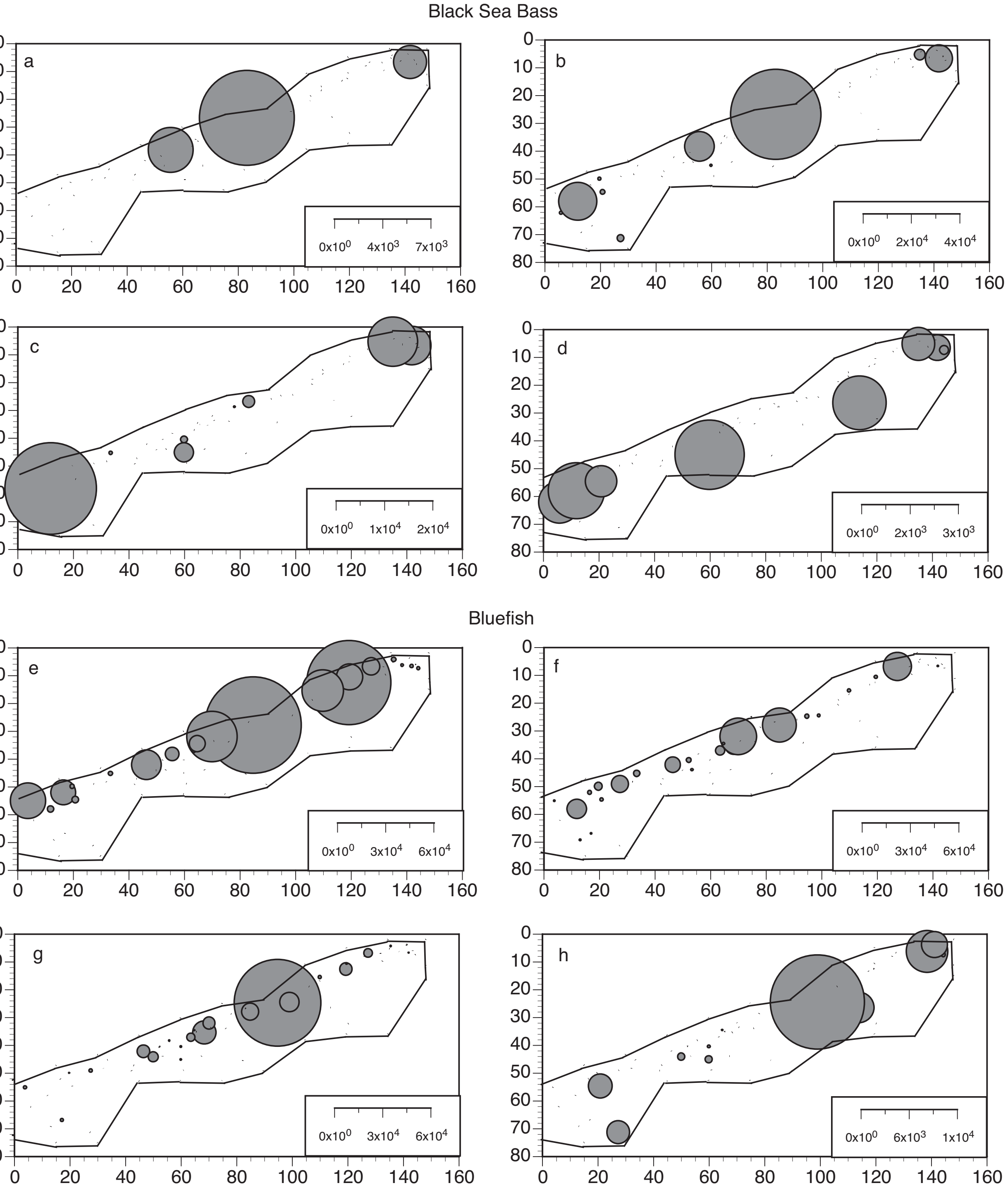

FIG. 5. – Area-weighted abundance (kg) assigned to each station occupied by the commercial vessel for black sea bass for individuals: A) 7-18 cm; B) 19-29 cm; C) 30-40 cm; D) 41-51 cm; and for bluefish for individuals: E) 7-24 cm; F) 25-41 cm; G) 42-58 cm; H) 59-74 cm. X and y axes are in km with the (0,0) point at 40°58.47'N, 73°36.71'W. The Delaunay domain is outlined.

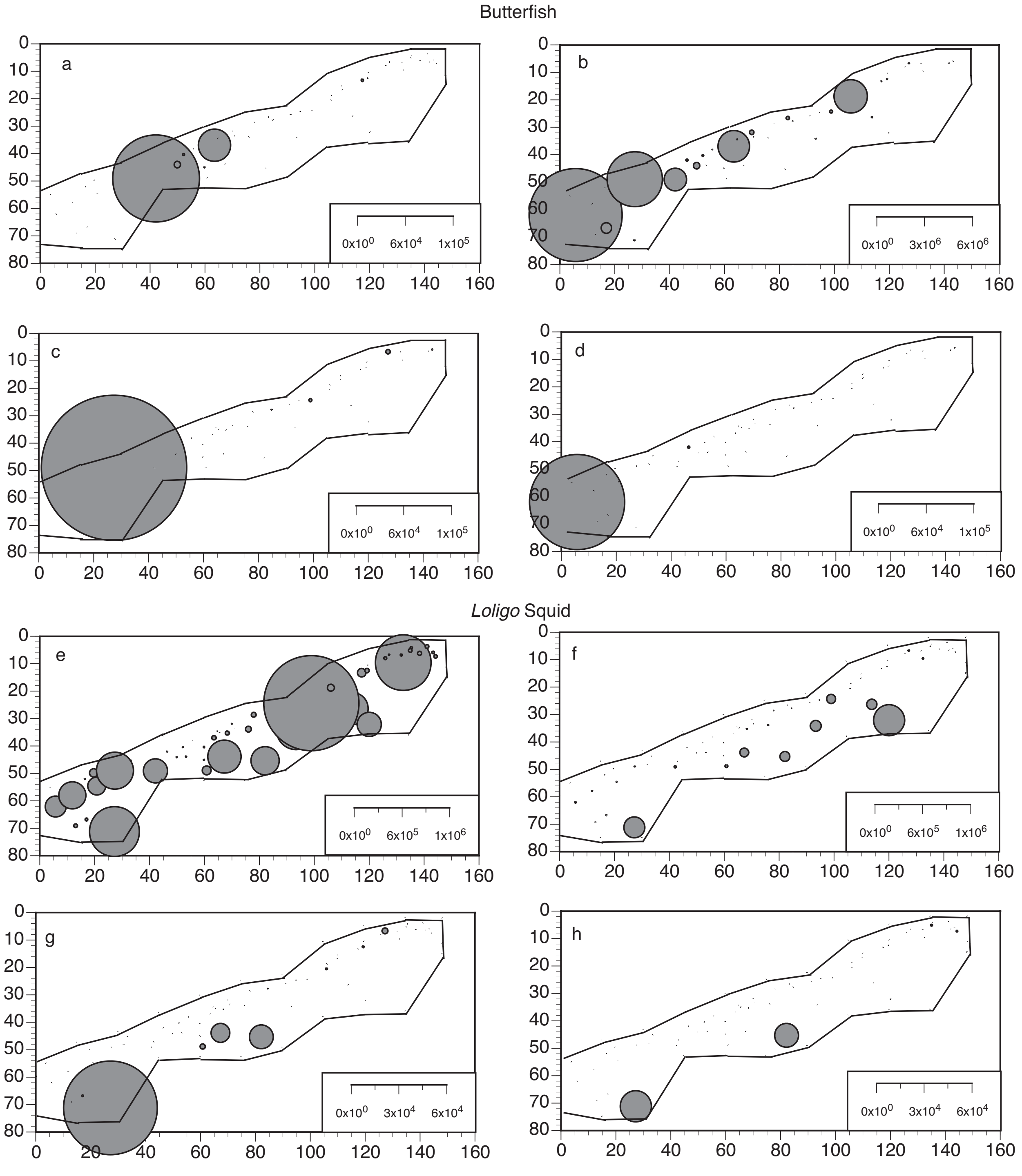

FIG. 6. – Area-weighted abundance (kg) assigned to each station occupied by the commercial vessel for butterfish for individuals: A) 7-11 cm; B) 12-15 cm; C) 16-19 cm; D) 20-22; and for *Loligo* squid for individuals: E) 7-12 cm; F) 13-17 cm; G) 18-22 cm; H) 23-29 cm. See Figure 5 for further explanation.

shore. In the second case, the larger fish were caught in the northeastern sector and the smaller fish in the southwestern sector.

Three species were distributed in an inshore-offshore gradient according to size. Small black sea bass (<30 cm) were caught in greatest numbers in the inshore half of the sampled domain (Fig. 5a,b). Large catches occurred sporadically over much of this area. Larger black sea bass were caught most commonly farther offshore, but throughout the offshore portion of the sampled domain (Fig. 5d). Small *Loligo* squid, like small black sea bass, tend-

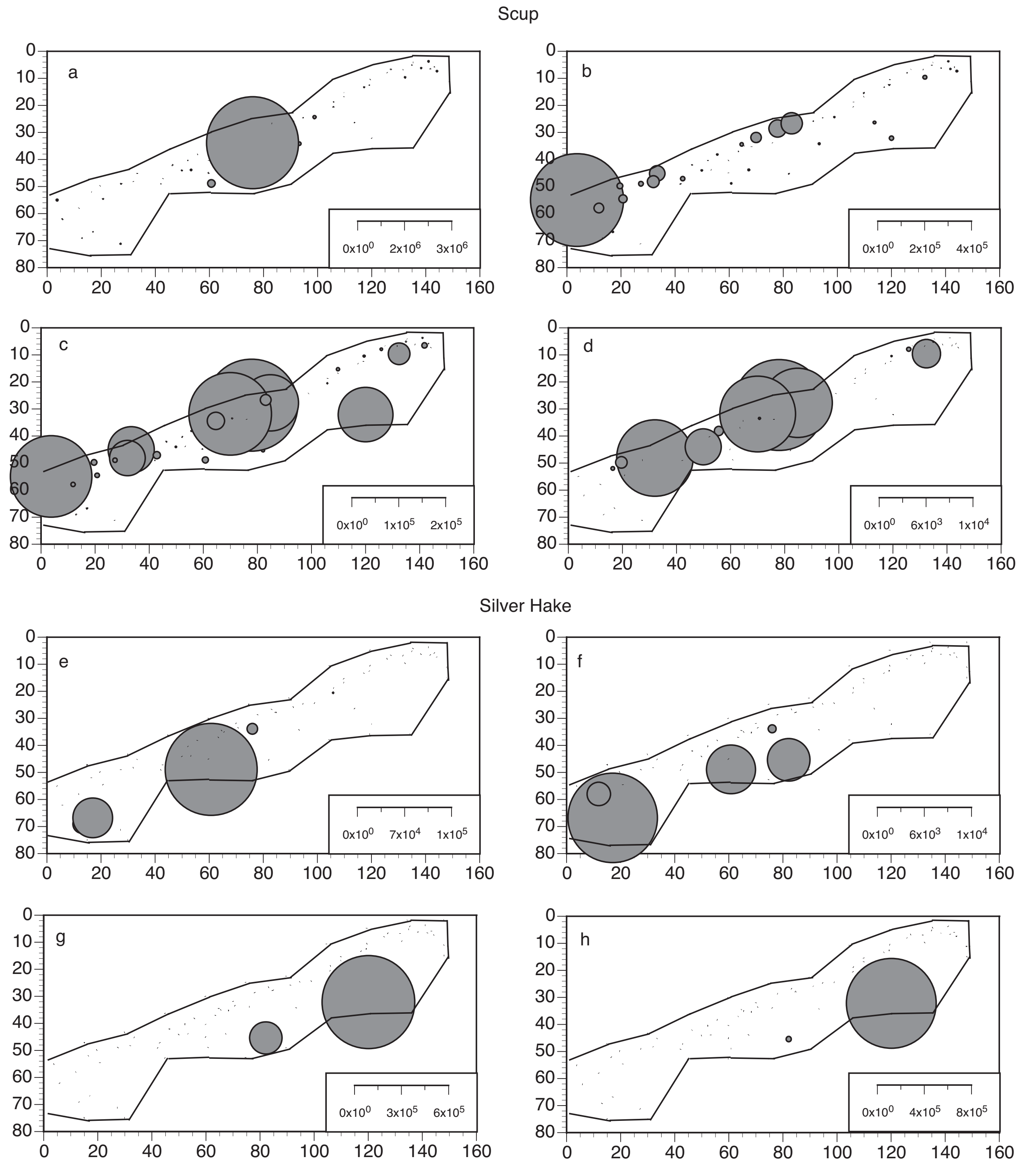

FIG. 7. – Area-weighted abundance (kg) assigned to each station occupied by the commercial vessel for scup for individuals: A) 7-14 cm; B) 15-21 cm; C) 22-28 cm; D) 29-35 cm; and for silver hake for individuals: E) 7-12 cm; F) 13-17 cm; G) 18-22 cm; H) 23-29 cm. See Figure 5 for further explanation.

ed to be caught inshore of the larger individuals (Fig. 6e,h). Catches of individuals <18 cm were distributed throughout much of the domain (Fig. 6e,f). Large individuals tended to be near the offshore boundary of the domain and were caught in proportionately fewer tows (Fig. 6g,h). Summer flounder were also distributed in an inshore-offshore gradient according to size (Fig. 8e-h). Small summer flounder (≤24 cm) were caught inshore, but sporadically in only a few tows (Fig. 8e). Somewhat larger fish

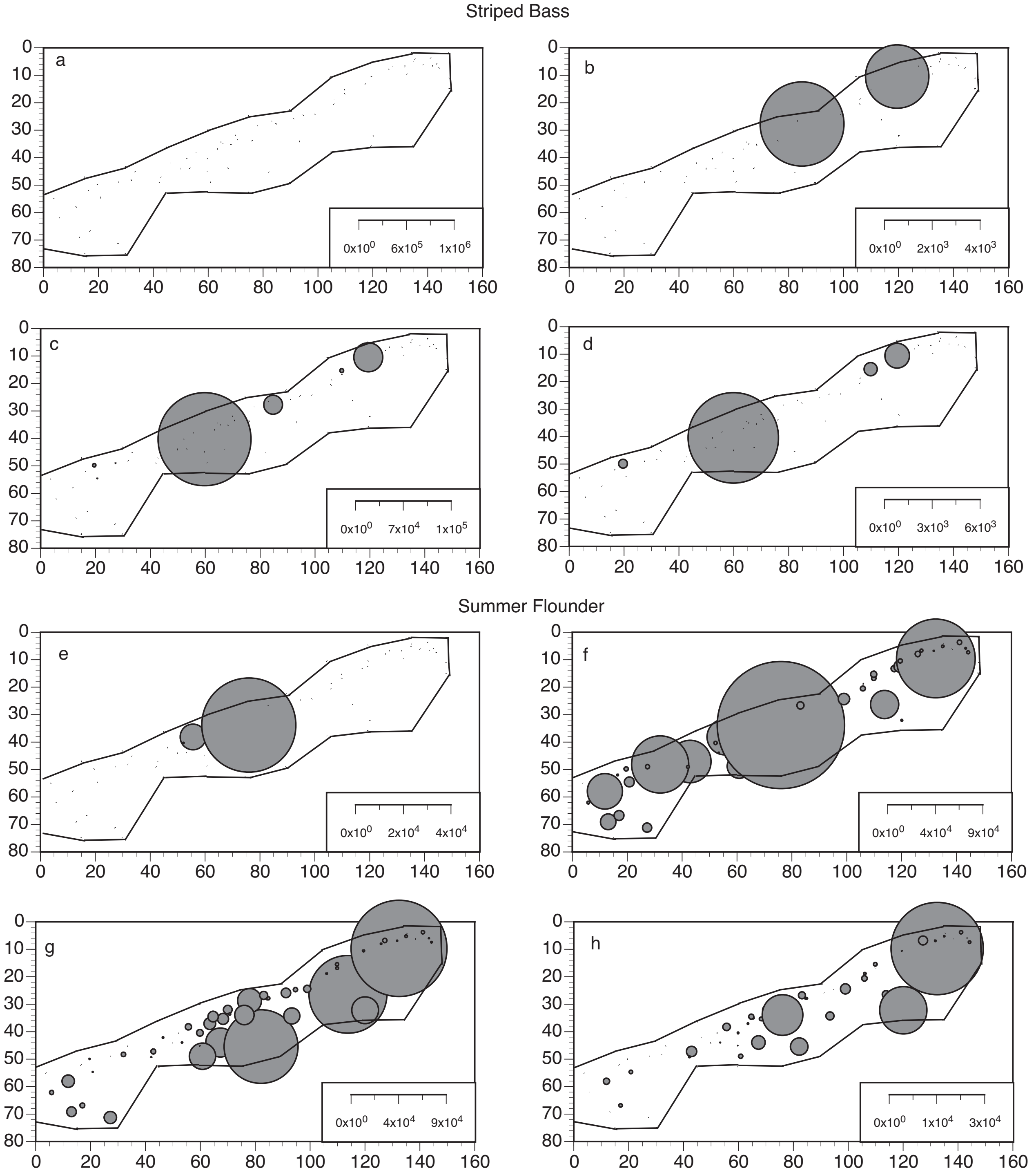

FIG. 8. – Area-weighted abundance (kg) assigned to each station occupied by the commercial vessel for striped bass for individuals: A) 33-57 cm; B) 58-82 cm; C) 83-108 cm; and for summer flounder for individuals: E) 7-24 cm; F) 25-41 cm; G) 42-58 cm; H) 59-76 cm. See Figure 5 for further explanation.

(25-41 cm) were caught nearly ubiquitously in the inshore half of the domain (Fig. 8f). Larger fish tended to be caught more frequently offshore and more frequently in the southeastern sector of the sampled domain (Fig. 8g,h).

The distributions of butterfish, weakfish, and silver hake were substantially different from the previous three. Most butterfish were caught in the southwestern sector of the sampled domain, regardless of size (Fig. 6a-d), although 12 to 15-cm fish were

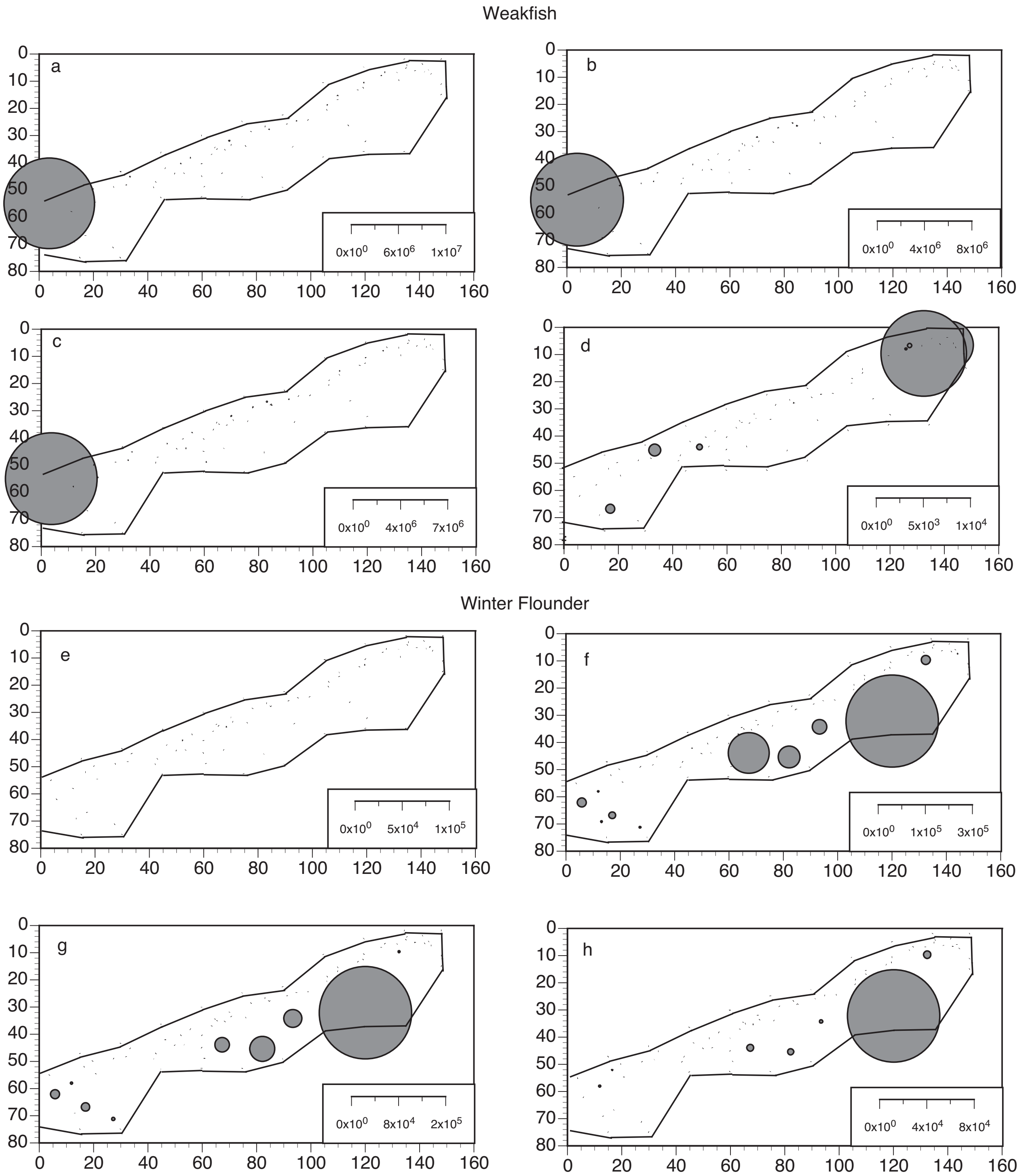

FIG. 9. – Area-weighted abundance (kg) assigned to each station occupied by the commercial vessel for weakfish for individuals: A) 7-24 cm; B) 25-41 cm; C) 42-58 cm; D) 59-76 cm; and for winter flounder for individuals: E) 17-25 cm; F) 26-34 cm; G) 35-44 cm. See Figure 5 for further explanation.

more widely dispersed (Fig. 6b). A few tows accounted for most of the fish caught. Silver hake were caught nearly exclusively in the offshore portion of the domain (Fig. 7e-h). The smaller size classes, like butterfish, tended to be caught in the southwestern sector (Fig. 7e,f). Larger silver hake (>17 cm) were caught predominately offshore in the northeastern sector of the domain (Fig. 7g,h). Most weakfish were also caught inshore in the southwestern sector of the domain (Fig. 9a-c). The exception were the largest fish that were caught inshore, but in the northeastern corner (Fig. 9d).

In contrast to the last two groups of species, largest bluefish catches occurred inshore over much of the sampled region (Fig. 5e-h). The largest fish (>58 cm) were caught proportionately more often in the largest tows (Fig. 5h). Scup catches also occurred predominately in the inshore half of the sampled domain (Fig. 7a-d). Larger scup were distributed throughout much of this region (Fig. 7c,d). Smaller scup tended to be encountered more sporadically (Fig. 7a,b). Striped bass were also caught predominately inshore (Fig. 8a-b). The smaller size classes were caught in only a few tows (Fig. 8a).

Winter flounder were caught offshore and preferentially in the southeastern sector of the sampled domain (Fig. 9e-g). The larger sizes tended to be caught in proportionately fewer tows, but in the same general region as the smaller fish.

Vessel comparisons of size frequency

The likelihood that the domain-average size-frequency distribution from the survey vessel, obtained from 18 tows could be obtained from an 18-tow subset of the 59 tows conducted by the commercial vessel was assessed using a Monte Carlo test and the 25th, 50th, and 75th percentile ranks and the mean size as the test metrics.

In three of ten cases, the 25th percentile size measured by the survey vessel fell outside estimates of the 95% confidence limits of the 25th percentile from the 18-station subset of the commercial vessel's 59-tow dataset (Table 6). This frequency is greater than expected by chance ($P < 0.02$). The equivalent occurrences for the 50th and 75th percentiles and the mean size were four of ten, four of ten, and six of 10 ($P < 0.001$, 0.001, 0.0000002 respectively). Thus, more often than anticipated by chance, the domain-average size-frequency distributions for the survey vessel diverged from those of the commercial vessel. Of particular note were the following species: bluefish, silver hake, weakfish, *Loligo* squid, butterfish, and summer flounder. For these species, one or more of the 25th, 50th, and 75th percentiles or the mean size differed significantly between the domain-average size-frequency distributions as measured by the two vessels. With one exception, the mean size for butterfish, significant differences between the two domain-average size-frequency distributions occurred because the percentile rank or mean size measured by the survey vessel was lower than expected from the 18-tow subset of the 59 tows taken by the commercial vessel.

Patchiness of the size classes

A patchy or contagious distribution of sample units among samples is typically identified by a variance-to-mean ratio significantly greater than 1.0 (Elliott, 1977; Powell *et al.*, 1987a,b). All size classes were patchily distributed in the commercial vessel catches, in the sense that the number of individuals caught per tow was contagiously distributed among the tows (Table 4). Thirty-seven of 37 cases is very unlikely to occur by chance ($P < 1x10^{-7}$). In 5 of 8 cases, the variance-to-mean ratio for the smallest individuals was significantly above 1.0, indicating a patchy or contagious distribution. This is a frequency greater than expected by chance ($P < 0.01$). In 5 of 8 cases, the largest individuals were least contagiously distributed, also a frequency greater than expected by chance ($P < 0.01$). Thus, smaller

TABLE 4. – Elliott's D and significance levels computed for the species listed in Table 1 (the commercial vessel). Elliott's D was calculated for each of four size classes defined by splitting the size range from 7 cm to the largest individual captured in the tow series into four even groups. The upper size boundary for each group is listed under the category 'Size'. The value for Elliott's D is listed in the third column to the right of each category, after the column describing the type of distribution pattern: C, a significant contagious distribution of sample values (catch numbers) among the samples; E, a significant even distribution; R, a random distribution.

	Small			Medium Small			Medium Large			Large		
Species	Size	D	D-value	Size	D	D-value	Size	D	D-value	Size	D	D-value
Black sea bass	18	C	14.38	29	C	36.27	40	C	32.67	51	C	4.35
Bluefish	24	C	36.77	41	C	21.74	58	C	23.79	74	C	12.83
Butterfish	11	C	304.25	15	C	44.85	19	C	39.01	—	—	—
Loligo squid	12	C	117.86	17	C	76.47	22	C	25.54	29	C	21.69
Scup	14	C	389.75	21	C	151.65	28	C	125.85	35	C	2.16
Silver hake	12	C	24.52	17	C	4.99	22	C	56.70	29	C	74.00
Striped bass	—	—	—	57	C	8.28	82	C	49.11	108	C	7.63
Summer flounder	24	C	42.23	41	C	65.15	58	C	33.33	76	C	6.94
Weakfish	24	C	877.02	41	C	728.52	58	C	665.43	76	C	3.44
Winter flounder	—	—	—	25	C	34.59	34	C	23.37	44	C	21.53

TABLE 5. – Elliott's D computed for four size classes for each of the species listed in Table 2 (the survey vessel). See Table 4 for further explanation.

	Small			Medium Small			Medium Large			Large		
Species	Size	D	D-value	Size	D	D-value	Size	D	D-value	Size	D	D-value
Black sea bass	—	—	—	29	C	10.79	40	R	1.22	51	R	0.34
Bluefish	24	C	101.40	41	C	3.89	58	R	0.82	74	R	-0.20
Butterfish	11	C	108.08	15	C	59.60	19	C	31.08	22	C	24.50
Loligo squid	12	C	35.64	17	C	13.22	22	C	2.48	29	R	0.09
Scup	14	C	29.61	21	C	28.88	28	C	16.83	35	R	-0.09
Silver hake	12	R	12.83	—	—	—	—	—	—	—	—	—
Striped bass	—	—	—	—	—	—	—	—	—	—	—	—
Summer flounder	—	—	—	41	C	6.73	58	C	4.27	76	C	3.37
Weakfish	24	C	30.12	41	C	3.33	58	R	1.42	76	R	0.12
Winter flounder	—	—	—	25	C	3.01	34	R	0.00	44	R	-0.65

individuals were normally contagiously distributed and normally, but not always, more contagiously distributed than larger individuals.

The distribution of individual catches for the survey vessel differed substantially from the pattern established for the commercial vessel (Table 5). In eleven of 30 cases, the distribution of individuals per tow among tows was random (a variance-to-mean ratio not significantly different from 1.0), rather than contagious. This frequency of occurrence of random distributions of sample values among samples was significantly greater for the survey vessel than for the commercial vessel (P $<2x10^{-7}$). Nevertheless, the tendency for the smallest individuals to be most patchily distributed and the largest individuals to be least patchily distributed was clear (Table 5). In only one case of 14, silver hake, was either of the two smaller size classes randomly distributed. Ten of 16 cases were random in the two larger size classes; for the largest size class, only summer flounder and butterfish were contagiously distributed. Thus, the survey vessel catches tended to be less variable than the commercial vessel catches, the lower variance being generated by a smaller range of catch values, particularly for the larger fish; but the tendency for the smallest individuals to be characterized more frequently by a larger variance in catch was similarly present.

The tendency of small individuals to be more patchily distributed can be readily observed from plots of area-weighted abundance (Figs. 5-9). In the extreme cases, large numbers of small scup, weakfish, and butterfish were caught in only a few tows, whereas the larger individuals tended to be dispersed more uniformly amongst the tows (Figs. 6-7 and 9). Even in less extreme cases, black sea bass and striped bass (Figs. 5 and 8), the contagious distribution of individuals among tows was readily apparent.

TABLE 6. – The percentile rank attained by the measured domain-average size-frequency metrics for the survey vessel within the probability distribution of size-frequency metrics obtained for 1,000 randomly-chosen 18-station subsets of the 59 stations sampled by the commercial vessel. The null hypothesis is that the measured metric, e.g., the 25th percentile of size, equals the 50th percentile of the probability distribution, a value of 0.5. Measured metrics significantly different from this expectation are identified by a percentile rank ≤0.05 or ≥0.95.

Species	25th percentile	Median	75th percentile	Mean
Black sea bass	0.482	0.429	0.250	0.340
Bluefish	0.0001	0.0001	0.0001	0.0001
Butterfish	0.520	0.887	0.546	1.000
Loligo squid	0.141	0.262	0.073	0.041
(diel-corrected)	0.141	0.0001	0.073	0.005
Scup	0.162	0.433	0.353	0.362
Silver hake	0.031	0.033	0.034	0.0001
Striped bass	0.901	0.498	0.184	0.313
Summer flounder	0.528	0.195	0.058	0.145
Weakfish	0.0001	0.010	0.004	0.002
Winter flounder	0.807	0.274	0.608	0.585

The relationship of catch distributions was examined by comparing the variance-to-mean ratios for sample groupings with an equivalent sample size. If sampling by the two vessels was characterized by equivalent distribution functions and equivalent sample numbers, the variance-to-mean ratios would not vary significantly more frequently than expected by chance. Whenever catches allowed, we examined all four size classes for each of the ten species measured. In 24 of 30 cases, the variance-to-mean ratio of the catches by the commercial vessel was higher, a frequency not expected by chance (binomial test, $P < 10^{-7}$) (Table 7). In two of 30 cases, the variance-to-mean ratio was higher for the survey vessel, a frequency no greater than expected by chance (binomial test, $P = 0.30$) (Table 7). Of the four cases where the variance-to-mean ratios obtained by the two vessels were not significantly different, three of four occurred in the upper half of the size-frequency

TABLE 7. – The percentile rank attained by the observed variance-to-mean ratio for each of four size classes defined in Table 5 for the 18-tow series of the survey vessel within the probability distribution of variance-to-mean ratios obtained for 1,000 randomly-chosen 18-station subsets of the 59 stations sampled by the commercial vessel. The null hypothesis is that the variance-to-mean ratio of the survey vessel equals the 50th percentile of the probability distribution, a value of 0.5. Measured variance-to-mean ratios significantly different from this expectation are identified by a percentile rank ≤0.05 or ≥0.95. The value 1.000 indicates a percentile rank >0.9999. The value 0.0001 indicates a percentile rank <0.0001.

Species	Small Probability	Medium Small Probability	Medium Large Probability	Large Probability
Black sea bass	—	0.002	0.0001	0.0001
Bluefish	1.000	0.0001	0.0001	0.009
Butterfish	0.007	1.000	0.370	—
Loligo squid	0.012	0.009	0.031	0.0001
Scup	0.053	0.031	0.043	0.142
Silver hake	0.047	—	—	—
Striped bass	—	—	—	—
Summer flounder	0.0001	0.014	0.001	0.168
Weakfish	0.190	0.002	0.0001	0.009
Winter flounder	—	0.009	0.0001	0.002

TABLE 8. – Fraction of total domain abundance (in individuals) contributed by area-weighted large catches. Large catches were defined as those catches greater than or equal to 25% or 50% of the largest catch in the tow series for each vessel for each of the size classes defined in Table 4.

	Small	Medium Small	Medium Large	Large
Large catches = ≥50% of largest catch				
Black sea bass	0.41	0.40	0.58	0.64
Bluefish	0.47	0.52	0.36	0.32
Butterfish	0.65	0.54	0.92	0.94
Loligo squid	0.33	0.45	0.61	0.94
Scup	0.75	0.38	0.73	0.70
Silver hake	0.57	0.58	0.71	0.91
Striped bass	—	1.00	0.62	0.66
Summer flounder	0.78	0.35	0.42	0.39
Weakfish	0.97	0.98	0.85	0.80
Winter flounder	—	0.38	0.44	0.73
Large catches = ≥25% of largest catch				
Black sea bass	0.90	0.82	0.74	0.97
Bluefish	0.79	0.74	0.46	0.73
Butterfish	0.90	0.78	0.92	0.94
Loligo squid	0.74	0.87	0.77	0.94
Scup	0.75	0.38	0.80	0.91
Silver hake	0.81	0.97	0.95	0.91
Striped Bass	—	1.00	0.82	0.84
Summer flounder	0.99	0.98	0.85	0.80
Weakfish	0.97	0.98	0.85	0.80
Winter flounder	—	0.72	0.73	0.73

distribution (Table 7). On the average, the variance-to-mean ratios of the two vessels were in closer agreement in the larger size classes where the variance-to-mean ratio was typically lower; that is, where the distribution of individuals was less patchy.

Influence of sample number

As a result of the patchy distribution of most species, the fraction of the animals caught in large catches, defined as catches containing ≥25% or ≥50% of the largest area-weighted catch in the tow series, was high (Table 8), typically, contributing 50% and often more than 85% to the estimate of total abundance for that size class. Thus, the contagious nature of catches makes more likely the possibility that limited sampling intensity in the domain might bias the area-weighted size-frequency distribution. The percentile sizes for the 59-tow commercial-vessel dataset rarely fell outside of the 50% confidence limits defined by a 15-tow subset using Monte Carlo tests, however, and never more frequently than expected by chance ($P > 0.10$) (Table 9). Thus, limiting sample size by a factor of four did not significantly influence the domain-average size-frequency distribution, despite the patchy distribution of the size classes noted previously (Tables 4 and 5).

Spatial distribution of species and size classes

The commercial vessel took a sufficient number of tows, 59, to examine the spatial distribution of ten species in more detail. For five of these, black sea bass, scup, silver hake, striped bass, and winter flounder, the population as a whole was randomly distributed in the sampling domain. Five others, bluefish, butterfish, *Loligo* squid, summer flounder, and weakfish, were patchily distributed. The number of species-size class combinations that demonstrated significant positive spatial autocorrelation exceeded the number expected by chance (10 of 37:

TABLE 9. – The percentile rank attained by the 59-tow domain-average size-frequency metrics for the commercial vessel within the probability distribution of size-frequency metrics obtained for 1,000 randomly-chosen 15-tow subsets of the 59 stations. See Table 6 for further explanation.

Species	Probability 25th percentile	Probability Median	Probability 75th percentile	Probability Mean
Black sea bass	0.380	0.442	0.386	0.364
Bluefish	0.651	0.572	0.671	0.614
Butterfish	0.533	0.361	0.572	0.347
Loligo squid	0.651	0.767	0.852	0.802
(diel-corrected)	0.659	0.806	0.892	0.833
Scup	0.149	0.153	0.266	0.249
Silver hake	0.741	0.740	0.731	0.731
Striped bass	0.594	0.553	0.392	0.436
Summer flounder	0.521	0.501	0.437	0.400
Weakfish	0.670	0.391	0.325	0.263
Winter flounder	0.373	0.289	0.681	0.637

TABLE 10. – Moran's *I* and Geary's *C* values for catch (individuals tow^{-1}) by the commercial vessel for the four size classes defined in Table 4. NS, not significant at $\alpha = 0.05$.

	Small		Medium Small		Medium Large		Large	
	Statistic	Probability	Statistic	Probability	Statistic	Probability	Statistic	Probability
Moran's *I*								
Black sea bass	-0.025	NS	-0.029	NS	-0.018	NS	-0.027	NS
Bluefish	-0.032	NS	-0.031	NS	-0.023	NS	0.037	P<0.005
Butterfish	-0.030	NS	-0.030	NS	-0.010	P<0.01	—	—
Loligo squid	0.000	P<0.01	-0.020	NS	-0.019	NS	-0.021	NS
Scup	-0.024	NS	-0.013	NS	-0.017	NS	-0.022	NS
Silver hake	-0.011	NS	0.005	P<0.005	-0.017	NS	-0.018	NS
Striped bass	—	—	-0.020	NS	-0.026	NS	-0.027	NS
Summer flounder	-0.022	NS	-0.019	NS	0.003	P<0.005	0.005	P<0.005
Weakfish	-0.011	P<0.05	-0.011	P<0.05	-0.011	P<0.05	-0.002	P<0.01
Winter flounder	—	—	-0.024	NS	-0.022	NS	-0.021	NS
Geary's *C*								
Black sea bass	1.121	NS	1.111	NS	0.850	NS	0.958	NS
Bluefish	1.021	NS	1.005	NS	1.086	NS	0.824	P<0.005
Butterfish	0.986	NS	0.919	NS	0.707	P<0.025	—	—
Loligo squid	1.008	NS	1.017	NS	0.902	NS	0.947	NS
Scup	1.142	NS	1.044	NS	1.123	NS	1.080	NS
Silver hake	0.987	NS	0.829	P<0.05	1.007	NS	0.995	NS
Striped bass	—	—	1.028	NS	1.082	NS	1.089	NS
Summer flounder	1.135	NS	1.117	NS	1.065	NS	1.027	NS
Weakfish	0.775	P<0.05	0.775	P<0.05	0.775	P<0.05	0.813	P<0.005
Winter flounder	—	—	1.052	NS	1.017	NS	1.011	NS

TABLE 11. – Moran's *I* and Geary's *C* values for the residuals obtained by predicting the catch (individuals tow^{-1}) by the commercial vessel of the second indicated size class from the first. Thus, the residuals for the left-most comparison between small and medium small individuals were computed by obtaining the expected value for the second indicated size class,

$$Medium\ Small_i = \frac{Small_i}{\sum_{i=1}^{n} Small_i} \times \sum_{i=1}^{n} Medium\ Small_i$$

and subtracting that value from the observed value. Size classes are defined in Table 4. NS, not significant at $\alpha = 0.05$.

	Small vs. Medium Small		Small vs. Medium Large		Small vs. Large		Medium Small vs. Medium Large		Medium Small vs. Large		Medium Large vs. Large	
	Statistic	Probability	Statistic	Probability	Statistic	Probability	Statistic	Probability	Statistic	Probability	Statistic	Probability
Moran's *I*												
Black sea bass	-0.026	NS	-0.020	NS	-0.024	NS	-0.022	NS	-0.027	NS	-0.015	NS
Bluefish	-0.031	NS	-0.027	NS	0.000	P<0.025	-0.025	NS	0.010	P<0.025	0.006	P<0.005
Butterfish	-0.038	NS	-0.022	NS	—	—	-0.037	NS	—	—	—	—
Loligo squid	-0.016	NS	-0.011	NS	-0.025	NS	-0.015	NS	-0.021	NS	-0.013	NS
Scup	-0.025	NS	-0.026	NS	-0.025	NS	-0.018	NS	-0.024	NS	-0.025	NS
Silver hake	-0.020	NS	-0.008	NS	-0.008	NS	0.001	P<0.005	-0.003	P<0.01	-0.021	NS
Striped bass	—	—	—	—	—	—	-0.019	NS	-0.020	NS	-0.024	NS
Summer fflounder	-0.025	NS	-0.025	NS	-0.021	NS	-0.020	NS	-0.017	NS	-0.017	NS
Weakfish	-0.013	NS	-0.022	NS	-0.004	P<0.005	-0.006	P<0.025	-0.004	P<0.005	-0.004	P<0.005
Winter flounder	—	—	—	—	—	—	-0.027	NS	-0.022	NS	-0.021	NS
Geary's *C*												
Black sea bass	1.039	NS	0.968	NS	1.065	NS	0.995	NS	1.100	NS	0.928	NS
Bluefish	0.990	NS	1.066	NS	0.909	P<0.01	1.063	NS	0.900	P<0.025	0.934	NS
Butterfish	0.941	NS	0.790	P<0.025	—	—	0.813	P<0.025	—	—	—	—
Loligo squid	0.985	NS	0.898	NS	0.959	NS	0.934	NS	0.963	NS	0.931	NS
Scup	1.134	NS	1.146	NS	1.117	NS	1.038	NS	1.078	NS	1.106	NS
Silver hake	1.032	NS	0.993	NS	0.985	NS	0.924	NS	0.941	NS	1.054	NS
Striped bass	—	—	—	—	—	—	1.097	NS	1.103	NS	1.125	NS
Summer flounder	1.138	NS	1.139	NS	1.131	NS	1.108	P<0.025	1.096	NS	1.076	NS
Weakfish	0.940	NS	0.978	NS	0.770	P<0.025	0.836	P<0.05	0.770	P<0.025	0.770	P<0.025
Winter flounder	—	—	—	—	—	—	1.093	NS	1.021	NS	0.992	NS

$P < 0.00001$ for a = 0.05). All significant differences were due to positive spatial autocorrelation, a spatially patchy distribution. Of those species that were randomly distributed as a whole, none but silver hake demonstrated any spatial distribution at the size-class level (Table 10). Of those species that were patchily distributed as a whole, all demonstrated some spatial structure at the size-class level, indicating that the significant spatial structure of the species was actually a property of one or more of the size classes (Table 10). Interestingly, of the species characterized by significantly different size-frequency distributions between the two boats (Table 4), bluefish, butterfish, *Loligo* squid, silver hake, summer flounder and weakfish, all but silver hake were characterized by positive spatial autocorrelation, a patchy distribution. None of the species in which the estimates of domain-average size-frequency distributions obtained by the two vessels were similar, black sea bass, scup, striped bass, and winter flounder, were so characterized.

The possibility that size classes of a species were significantly differentially distributed in space was assessed by analyzing the residuals obtained by predicting one size class' distributional pattern from the other. The spatial arrangement of the size classes of species that did not show significant spatial autocorrelation, black sea bass, scup, striped bass, and winter flounder, were not significantly different from each other (Table 11). For the remaining species, bluefish, butterfish, *Loligo* squid, silver hake, summer flounder and weakfish, the smaller size classes tended to have spatial distributions significantly different from the larger size classes of the same species (Table 11). In particular, size classes 1 and 2 were never significantly different in their distribution patterns for any species and size class 1 was significantly different from size class 3 in only one case. The remaining significant differences all occurred in comparisons between the distributional patterns of size classes 3 and 4 with themselves and with the smaller size classes.

Directional spatial autocorrelation

For the silver hake, summer flounder, butterfish, and winter flounder populations as a whole, positive autocorrelation was greatest at angles of 0.79-1.18 radians (45°-67°) from the north-south axis. The preferred direction of population orientation tended to parallel the shoreline, an angle of 60°, in these species. For the black sea bass, *Loligo* squid, and weakfish populations as a whole, the preferred orientation was 1.57-2.16 radians (90°-124°). The preferred orientation of these species included an offshore component as well as an alongshore component. Scup, striped bass, and bluefish were not directionally distributed.

Negative spatial autocorrelation tended to be maximal at angles somewhat higher than those generating positive spatial autocorrelation. That is, translating the angle to a more offshore component tended to reduce positive and increase negative spatial autocorrelation. In cases where both a preferred and non-preferred direction were significant, the change in angle between the preferred and non-preferred direction was always less than 90° and often no more than 11-34°.

With the exception of striped bass, all species had some degree of significant directionality in their spatial distribution for at least one size class (Table 12). For the four species whose domain-average size-frequency distribution did not differ between boats, black sea bass, scup, striped bass and winter flounder, 11 of 28 tests were significant. Of the 11, 6 were for winter flounder. For the six species whose domain-average size-frequency distribution differed between boats, bluefish, butterfish, *Loligo* squid, silver hake, summer flounder, and weakfish, 32 of 46 tests were significant (Table 12). Both of these frequencies far exceed that expected by chance. The frequency of significant differences for the latter group (32 of 46) far exceeds that of the former ($P = 0.000012$). The preferred orientation varies among the size classes for all species save two, weakfish and winter flounder (Table 12). For these two, all significant results showed the same most-preferred direction for all size classes.

The differing directional pattern in the spatial distribution of size classes was confirmed using residual analysis. Size classes were frequently significantly differentially distributed in their spatial orientation for black sea bass, bluefish, *Loligo* squid, scup, summer flounder, and winter flounder.

DISCUSSION

Perspective

An accurate evaluation of the size-frequency distribution is a requirement of most stock assess-

TABLE 12. – Most significant Moran's *I* values from directional spatial autocorrelation for each of the size classes defined in Table 4. Angles from a north-south direction were examined in $\pi/16$ increments: 0.00 (N-S), 0.20, 0.39, 0.59, 0.79, 0.98, 1.18, 1.37, 1.57 (E-W), 1.77, 1.96, 2.16, 2.36, 2.55, 2.75, and 2.95 radians. NS, not significant at $\alpha = 0.05$.

Species	Moran's *I*	Highest Significance	Angle	Moran's *I*	Lowest Significance	Angle
Black sea bass						
Small	0.015	NS	1.37	-0.677	NS	2.16
Medium Small	0.184	NS	1.77	-0.819	$P < 0.025$	2.16
Medium Large	0.665	$P < 0.005$	1.77	-0.496	$P < 0.05$	0.39
Large	2.221	$P < 0.005$	0.00	-0.575	NS	0.39
Bluefish						
Small	0.190	$P < 0.005$	1.18	-0.763	$P < 0.05$	2.16
Medium Small	0.118	$P < 0.005$	1.18	-0.187	NS	0.98
Medium Large	0.002	NS	1.18	-0.230	NS	1.96
Large	2.154	$P < 0.005$	2.36	-0.086	NS	1.18
Butterfish						
Small	0.179	NS	1.57	-0.961	$P < 0.05$	2.36
Medium Small	0.052	NS	0.79	-1.284	$P < 0.005$	0.00
Medium Large	0.044	NS	0.98	-0.451	$P < 0.01$	1.96
Loligo squid						
Small	1.409	$P < 0.005$	0.39	-0.105	$P < 0.01$	1.18
Medium Small	0.132	$P < 0.005$	1.18	-2.487	$P < 0.005$	2.55
Medium Large	0.204	$P < 0.005$	0.98	-0.634	$P < 0.025$	0.59
Large	0.016	NS	1.57	-0.348	$P < 0.05$	0.79
Scup						
Small	0.201	$P < 0.005$	0.79	-0.049	NS	1.37
Medium Small	0.181	NS	0.39	-0.713	NS	2.55
Medium Large	0.098	NS	2.36	-0.287	NS	2.16
Large	0.008	NS	1.18	-0.678	NS	2.95
Silver hake						
Small	0.115	$P < 0.005$	1.18	-0.264	$P < 0.005$	0.98
Medium Small	0.054	$P < 0.01$	1.18	-0.263	$P < 0.005$	0.98
Medium Large	0.030	$P < 0.05$	1.18	-0.251	$P < 0.005$	1.37
Large	0.019	$P < 0.05$	1.18	-0.209	$P < 0.005$	1.37
Striped bass						
Medium Small	0.034	NS	0.79	-0.558	NS	0.00
Medium Large	0.048	NS	1.96	-0.446	NS	0.00
Large	0.043	NS	0.59	-0.386	NS	0.00
Summer flounder						
Small	0.278	$P < 0.005$	1.37	-0.096	NS	0.79
Medium Small	0.215	$P < 0.01$	1.37	-0.228	NS	0.59
Medium Large	2.092	$P < 0.005$	2.16	-0.081	NS	1.18
Large	1.188	NS	2.16	-1.740	$P < 0.05$	2.55
Weakfish						
Small	0.010	$P < 0.01$	1.18	-0.524	$P < 0.005$	2.55
Medium Small	0.009	$P < 0.05$	1.18	-0.516	$P < 0.005$	2.55
Medium Large	0.009	$P < 0.05$	1.18	-0.531	$P < 0.005$	2.55
Large	0.265	NS	1.57	-0.065	NS	1.18
Winter flounder						
Medium Small	0.080	$P < 0.005$	1.18	-1.613	$P < 0.05$	2.55
Medium Large	0.077	$P < 0.005$	1.18	-1.880	$P < 0.005$	2.55
Large	0.029	$P < 0.025$	1.18	-1.407	$P < 0.005$	2.55

ments. From the size-frequency distribution comes an estimate of recruitment and also an evaluation of the influence of certain fisheries management measures. In particular, fisheries managers look for a truncation of the size-frequency distribution that is often associated with overfished stocks. In addition, the size-frequency distribution indirectly influences the status of the stock estimate, in that biases in the capture of the larger or smaller size classes may result in biases in stock biomass, spawning stock biomass, or recruitment estimates.

As most species are patchily distributed at the size class level, and as many species are characterized by size classes not equivalently spatially distributed, issues of sample density, adequacy of survey domain, and the degree to which multispecies strata are optimal for all species continuously arise. The solution is additional sampling, and, as a consequence, cooperative survey programs using commercial vessels as survey platforms have increased in frequency and complexity over the last decade (e.g. Karp *et al.*, 2001). The in-depth evaluation of the advantages and limitations of various deployment modes for these vessels and the degree to which data gaps of various types can be addressed by them is not well-studied, however. The purpose of this study was to evaluate the use of commercial vessels to increase sampling density and to reduce data gaps by increasing survey domain. Both require that the size-frequency distributions obtained from the survey and commercial vessels can be confidently compared as equivalent representations of the species' size-frequency distributions at the location sampled. Because the true size-frequency distribution cannot be known, and because no two sampling devices have equivalent catchabilities across all species and size classes, this necessary comparison requires an understanding of the relative catchabilities of the two gears. Because continued vessel-to-vessel comparisons are expensive and logistically complex, minimizing the continuing need for and extensiveness of direct comparisons is essential. Thus, comparability must be retained over a range of species' abundances that very likely is much larger than the range observed during vessel calibration. Whatever complexities exist in achieving comparability are increased when the survey and augmentation programs are multispecies.

Accordingly, we examined the use of tow data obtained by a commercial vessel to augment trawl surveys hampered by the normal logistical constraints imposed by limited survey time, large survey area, and simultaneous assessment of multiple species to improve the evaluation of the size-frequency distribution and to identify potential biases in biomass and abundance estimates produced by uncertainty in the size-frequency distribution. Analysis focused on elucidating the reasons for differing size-frequency distributions between vessels. These differences arise from varying sampling intensity and distribution, key *raisons d'être* for a cooperative survey program, and differing catchability, a key impediment to achieving the former goal. The experimental design involved a random sample of 18 tows taken by the survey vessel in the experimental domain offshore of Long Island, New York, approximately a threefold higher sampling intensity in the same domain by a commercial vessel, and a gradient in sampling intensity produced by an offset in the sampling domain and the configuration of sampling strata in the federal survey. The latter specifically tested the probability that defined strata were unlikely to provide optimal sampling intensity for all species.

Sample density and spatial distribution

Analysis focused on ten recreationally and commercially important species: bluefish, butterfish, *Loligo* squid, weakfish, summer flounder, winter flounder, silver hake (whiting), black sea bass, striped bass, and scup (porgy). These species fell into four categories. Some, such as black sea bass, *Loligo* squid, and summer flounder, demonstrated an onshore-offshore gradient such that smaller fish were caught disproportionately inshore and larger fish offshore. Others, including butterfish, silver hake, and weakfish, were characterized by a southwest-northeast gradient such that larger fish were caught disproportionately northeast of the southwestern-most sector. Fish of all sizes were caught predominately inshore for scup, striped bass, and bluefish, and predominately offshore for winter flounder. Effectively sampling species with differing distributional patterns within the sampled region is a typical challenge for a multispecies survey program.

The size-frequency distribution obtained by the survey vessel for six of the ten species could not be obtained by chance from the size-frequency distribution obtained by the commercial vessel. These species were bluefish, butterfish, summer flounder, weakfish, *Loligo* squid, and silver hake. In nearly all of these cases, the 75th percentile size was smaller for the survey vessel, indicating that the survey vessel tended to catch more small fish or fewer large fish.

Not surprisingly, the two vessels varied considerably in their apparent catchabilities among species and between size classes, as estimated from the ratio of mean catches (Table 3).

Potentially, the size-frequency distribution might vary between boats for three reasons. (1) Gear efficiency may be different for some size classes for the gears used by the two vessels (e.g. Walsh, 1992; Lök *et al*., 1997; Morales-Bojórquez *et al*., 2001). (2) Sample density may influence the domain-average size-frequency distribution (e.g. Findlay, 1982; Godø, 1994; Cao *et al.,* 2001). (3) The spatial arrangement of species as it interacts with sampling design may influence the final domain-average size-frequency distribution (e.g. Smith and Gavaris, 1993; Brodziak and Henderson, 1999). To identify factors possibly responsible for the observed differences in size-frequency distribution between boats, we assessed species distributional patterns using aspatial and spatial methods. The aspatial approach evaluates the distribution of sample values among samples regardless of the location of sample origin. The spatial approach emphasizes the location of samples and the sample values of neighboring stations.

Aspatial analysis revealed that the sample values obtained by the commercial vessel were routinely contagious. The variance-to-mean ratio was always significantly above 1.0. This was true for all size classes. In general, the smaller size classes were more patchily distributed than the larger size classes. The same analysis for the survey vessel revealed a tendency towards a more even dispersion of sample values among the samples. Likely this is due to the more limited range of large catches in the survey dataset (Powell *et al.*, in press). Comparison of the variance-to-mean ratios for the two boats revealed that the commercial vessel catches were significantly more contagious in 24 of 30 cases. Four of the six other cases, including both cases where the survey vessel catches were significantly more contagious than the commercial vessel catches and two of the four cases showing no significant difference, were cases where the ratio of catch means favored the survey vessel. These four cases are the only cases where the ratio of catch means favored the survey vessel (Table 3). Thus, the trends in relative catchability between the two vessels are primarily determined by the trends in the probability of large catches of species and size classes that directly determine the relative degree of contagion quantified by the the vessels' respective variance-to-mean ratios.

In a random sampling approach, some stations will contribute a larger fraction of total survey area than others. The distribution of fish, however, may not obey the sampling design, particularly if environmental gradients shift the structure of the fish population (e.g. Brandt and Wadley, 1981; Cadrin *et al.*, 1995) along a spatial gradient different from the gradient in sample density. Errors of some magnitude can be expected if areas of low sampling density yield the largest catches (see also Smith and Gavaris, 1993; van der Meer, 1997). Because large catches occur infrequently, a lower sampling intensity presents a greater risk of a biased estimate. If the large catches occur most frequently in the area of least sampling density, then the bias will likely be an underestimate of domain biomass or a biased size-frequency distribution because a large catch is more likely to be missed than sampled.

The commercial vessel took 59 tows in the domain and the survey vessel only 18. A gradient in station density existed in this domain. In the dataset obtained, large tows, defined as ≥50% of the largest tow, contributed 40% or more of the total catch in nearly all species. For some, such as butterfish, weakfish, and silver hake, the contribution was greater than 70% (Table 8). Nevertheless, a 15-tow subset of the 59-tow commercial dataset did not differ significantly from the 59-tow composite for any species or size class. Therefore, the simple lowering of sample density, while reducing the precision of the estimated domain-average size-frequency distribution, did not significantly influence basic descriptors such as the mean, median, or the interquartile range. It is unlikely that the differences observed between the two vessels can be ascribed simplistically to differences in sampling intensity. A subset of commercial tows differed in size frequency as much, or as little, from the survey vessel tows as did the full 59-tow dataset.

Neither a change in sampling density nor the simple comparison of aspatial differences between boats resolved the conundrum posed by the differing size-frequency distributions obtained by the two vessels. Indeed, species characterized as patchy by the commercial vessel and random by the survey vessel included those in which the size-frequency distributions significantly differed, such as bluefish and weakfish, and those in which it did not, such as black sea bass and winter flounder (Table 6). Very likely trends in the scale of patchiness across size classes documented by the tendency for the variance-to-mean ratio to decline with increasing size are similarly revealed by both vessels, albeit at different degrees of scale. Although the commercial vessel sees an inherently larger variance-to-mean ratio, this does not influence the size-frequency distribution to nearly the degree that it influences the overall catch weight. The commercial vessel was characterized by increased catchability for most species; normal survey vessel catches were less than 10% of commercial vessel catches (Powell *et al.,* in press). Thus, gear bias per se would appear an unlikely explanation for the significant differences in size-frequency distribution observed between the two vessels, though it likely accounts for some portion of the substantial difference in catch weights.

The influence of spatial arrangement

Examination of the spatial arrangement of samples revealed that no species or size class was characterized by an even distribution (negative spatial autocorrelation). Some were random. However, a suite of six species was patchily distributed (positive spatial autocorrelation): butterfish, bluefish, *Loligo* squid, summer flounder, weakfish, and silver hake. All but one of these species were positively spatially autocorrelated (patchy) at the population level and all had one or more size classes so characterized. Interestingly, these same species compose the species group characterized by significant differences in domain-average size-frequency distribution between the two boats, as judged by differences in the mean, median, or interquartile range. Interestingly, five of the six cases in which the variance-to-mean ratio was not significantly higher for the commercial vessel and three of four cases yielding a ratio of mean catches that favored the survey vessel came from this same species group. Thus, the origin of the significant differences in size-frequency distribution observed between vessels for these six species would appear to be the interaction of the spatial distributional pattern of the species with the spatial distribution of samples.

Interestingly, the six species do not fall into a coherent group based on the relative geographic distribution of the size classes. Butterfish, silver hake, and weakfish were characterized by smaller individuals more abundant in the southwestern corner and larger individuals more abundant to the northeast. Small individuals of summer flounder and *Loligo* squid were more common inshore; larger individuals were more common offshore. Bluefish were more abundant inshore in all size classes. However, five of the six species were characterized by size class differences across the domain that were obvious visually (Figs. 5-9) and all of the species were characterized by size class differences in distribution as evaluated by residual analysis. Thus, differential spatial patterns of the size classes within the sampled domain seem to be a primary generator of the differing domain-average size-frequency distributions observed between the two vessels.

Directional spatial patterns

The frequency of onshore-offshore and east-west gradients in distributional patterns conveyed by Figures 5-9 suggests that spatial patchiness might be better assessed using direction rather than distance as the defining criterion. Analysis of distributional pattern by an aspatial method, using Elliott's D statistic, revealed more patchiness than was revealed using spatial autocorrelation by Moran's *I* or Geary's *C*. One reason for this discrepancy may be asymmetry in patch configuration revealed by directional spatial autocorrelation. As suggested by visual inspection (Figs. 5-9), most species were oriented alongshore or alongshore with a moderate offshore component. In most cases, this orientation was significantly nonrandom. In most cases, species' orientation tended to be significantly different from the onshore-offshore perpendicular. However, these population trends in preferred orientation frequently failed to translate into consistent trends at the size class level. For species, such as *Loligo* squid, bluefish, and summer flounder, different size classes often had divergent directional trends in their distributional pattern. In sharp contrast were species, such as winter flounder, weakfish, and to a large extent, silver hake, with size classes that were more consistent in their preferred orientation. These differing trends were confirmed through residual analysis that clearly differentiated *Loligo* squid, bluefish, and summer flounder from the remainder of the species in the complexity of the species' spatial distribution at the size class level.

Nevertheless, with the exception of winter flounder, those species characterized by similar domain-average size-frequency distributions between the two vessels were characterized by a low incidence of significant directionality at the size class level. That is, size classes of these species tended to demonstrate no preferred direction of orientation more often than did those species that did show a significant difference in domain-average size-frequency distribution.

The exception, winter flounder, was one of two species characterized by the same preferred direction of orientation among all size classes showing a significant trend. These trends corroborate the importance of spatial structure in influencing the evaluation of domain-average size-frequency distribution, while also indicating that the asymmetry of the alongshore and offshore gradients in distribution compromised the inverse distance method that weighted sample pairs in autocorrelation analysis strictly by their distance apart. Offshore distance and alongshore distance are substantially different in their effect on spatial distributional patterns for many species.

CONCLUSIONS

In six of ten cases, the domain-average size frequencies obtained by the two vessels differed significantly. The origin of this difference was not simplistically related to catchability differences between the two vessels or sample density. The evidence suggests that inequities in the spatial arrangement of the sampling program for the two vessels with the spatial arrangement of the species is responsible. Inasmuch as failure of the vessel to demonstrate the expected trend towards decreased patchiness with increasing size normally characteristic of both vessels generated, with 100% frequency, significant differences between vessel size-frequency distributions, one can infer that the mechanism of interaction involves a change in the frequency of large catches for one or more size classes in one or both vessels produced by the spatial heterogeneity of species and sampling design. Certain species were characterized by one or more size classes in which the ratio of means favored the survey vessel. Certain species were characterized by some size classes in which the variance-to-mean ratio was not significantly different between vessels. These species account for the majority of instances where the size-frequency distribution was significantly different between the two vessels. These species also account for most of the significant trends in spatial distribution. It seems likely that spatial patchiness, particularly asymmetrical (directional) patchiness, increases the probability that the two vessels will diverge from their normal trends in relative catchability, and this predisposition creates the conditions necessary to generate divergent size-frequency distributions.

That fish are spatially patchy, that this spatial patchiness is related to water depth and environmental variables such as temperature, and that size classes of fish may be differentially distributed in space is well known (e.g. Perry and Smith, 1994; Fromentin *et al.*, 1997; Rogers *et al.*, 1999; Zheng *et al.*, 2001). What is surprising are the large differences in domain-average size-frequency distribution observed between the two vessels for the majority of species and the seeming basis for these differences in the interaction of one aspect of vessel catchability, the frequency of large catches, with spatial patchiness. These differences in size-frequency distribution exist despite a relatively intense sampling program in the survey domain even by the survey vessel. That vessel took 18 tows. Average tow distance on a Gabriel graph constructed from the station positions (Gabriel and Sokal, 1969) was 11.8 km. Average Gabriel distance between stations for the commercial vessel was about half this value: 5.8 km. The results emphasize the uncertainty in size-frequency distributions obtained even by relatively intensive survey efforts and the likelihood that increased spatial patchiness will increase the likelihood that any two sampling programs will obtain divergent estimates of the size-frequency distribution. The results emphasize the interaction of differential spatial arrangements of species' size classes with sampling efficiency. Because critical information for stock assessment is obtained from the size-frequency distribution and because certain size classes contribute disproportionately to stock biomass or abundance, uncertainty in the size-frequency distribution may generate uncertainty in the final stock assessment. The degree to which such uncertainty exists cannot be easily evaluated from a single vessel's data.

In cases where the two vessels obtained different size-frequency distributions, more large fish were present in the one obtained from the commercial vessel. Thus, when the size-frequencies diverged between the two vessels, a consistent bias existed. It is interesting that fishermen's anecdotes often relate to their belief that the survey vessel used in the Mid-Atlantic Bight undersamples larger fish. We cannot differentiate the likelihood that one vessel undersamples or the other oversamples large fish from this study, but we can provide some guidance as to the origin of the anecdotal view. Large fish are inherently more evenly distributed in space. As a consequence, the frequency of large catches is inherently lower. A vessel that tends, on the average, to have more large catches, will then have a much greater chance of obtaining the more unusual large catch in the size class most evenly spread out. As a consequence, that vessel's size-frequency distribution will be enriched in the larger size classes and that is what is observed. The goal of this study was to examine the use of commercial vessels to augment trawl-based multispecies stock surveys with particular emphasis on the use of commercial vessels to evaluate the influence of sampling density on the domain-average size-frequency distribution and the degree to which data collected by the two vessels could be standardized into a common database. The study shows that variations in the spatial arrangement of species and size classes with the sampling design are likely to generate differences in size-frequency distributions. The result is not unexpected. The study also shows, however, that the mechanism involves the interaction of the spatial distributional patterns with the catch dynamics of the two vessels that produces a significant variation in the frequency of large catches. Thus, one cannot conclude that size frequencies from each vessel are independent objective representations of the sampled population. A correction for sampling bias will be necessary to conflate the two datasets, if one of the two is not assumed to be inherently superior. What is surprising is the tendency for the significant differences to be produced by instances in which the normal sampling bias between the two vessels is voided by interaction between the spatial arrangement of fish and samples. This suggests that standardization between vessels in order to resolve the observed differences, if possible at all, will require attention to details of the sampling process rather than reliance upon average conversions.

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