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Evaluation of USA and Canadian Research Vessel Surveys and Survey Design in Assessing Abundance, Size Composition, and Recruitment of Sea Scallops on Georges Bank

by

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SPECIAL SESSION ON BIOLOGICAL SURVEYS

ABSTRACT

Independent, annual sea scallop research vessel surveys were conducted by the USA and Canada during 1982-1984 in the Northern Edge and Peak region of Georges Bank. Despite sampling design differences between the USA and Canadian surveys, statistically comparable estimates of relative abundance, population size composition, and recruitment levels were obtained from the two surveys in each year. Potential factors contributing to this concordance of results are discussed and evaluated with respect to survey design considerations, sampling intensity, and future survey activities.

INTRODUCTION

Since the mid-1970's, the USA and Canada have independently conducted annual research vessel surveys of sea scallop, Placopecten magellanicus (Gmelin), populations on Georges Bank to evaluate trends in abundance, size/age composition, and recruitment. Results from both survey series have been used to assess resource and fishery status and to forecast future stock conditions (Serchuk et al. 1979, 1982; Jamieson et al. 1981; Robert et al. 1982; Serchuk 1983; Mohn et al. 1984, 1985; Serchuk and Wigley 1984). Scientific advice developed from the survey analyses has been rendered to resource managers in both nations to impart an understanding of the biological basis of the sea scallop fisheries.

Although similar sampling gear are used in both USA and Canadian surveys, the survey sampling designs differ. The USA survey employs a stratified random design with scallop sampling strata based on water depth and latitude; the Canadian survey uses a stratified random scheme with sampling strata based on commercial catch per unit of effort contours derived prior to each survey.

During 1982-1984, separate but seasonally concurrent (summer) annual scallop surveys were conducted by each country in the Northern Edge and Peak region of Georges Bank. In all three sets of surveys, identical types of data on scallop catch and size composition were recorded. Copies of the survey logs were exchanged between countries affording access to both USA and Canadian scientists to all of the survey information. Hence, comparative analyses were able to be performed evaluating the consistency and accuracy of results obtained from the two survey series.

This paper presents the findings of these analyses and examines the comparability of estimates of sea scallop abundance, size composition, and recruitment derived from USA and Canadian scallop surveys conducted in each of the past three years. Spatial patterns in the distribution and abundance of scallops inferred from both survey series are also assessed and discussed in relation to survey design considerations.

MATERIALS AND METHODS

Research Vessels and Sampling Gear

USA scallop surveys during 1982-1984 were conducted using the R/V ALBATROSS IV (57 m long, 1130 horsepower, 988 gross mt), the vessel used in all previous USA scallop surveys. Sampling was performed with a standard 2.44 m (8 ft) wide commercial sea scallop dredge equipped with a 5.1 cm (2 in) ring bag and a 3.8 cm (1.5 in) polypropylene mesh liner to retain small scallops (Table 1). Detailed gear specifications are given in Serchuk and Smolowitz (1980).

Canadian scallop surveys were conducted with the R/V E.E. PRINCE (40 m long, 600 horsepower, 406 gross mt: Halliday and Koeller 1981). Tows were made with a 2.44 m (8 ft) wide New Bedford scallop dredge equipped with 7.62 cm (3 in) rings and a 3.8 cm (1.5 in) polypropylene stretch mesh liner.

Sampling Designs

In both USA and Canadian scallop surveys conducted during 1982-1984, stratified random sampling designs were employed. However, the stratification schemes used by each country were based on different variables. In the USA surveys, offshore areas between 27-110 m (15-60 fm) are stratified into geographical zones based on depth and latitude (Figure 1). Four depth zones are covered: 27-46 m, 46-55 m, 55-73 m, and 73-110 m. The survey area in the Northern Edge and Peak region of Georges Bank (latitude 40°48' to 42°09'N; longitude 65°55' to 68°28'W), encompassing 4,472 square nautical miles, is divided into 10 sampling strata (Table 2, Figure 2). Sampling stations are allotted to strata in proportion to stratum area and assigned randomly within each stratum. Additional randomly selected stations are frequently assigned to those strata in which either commercial fishing activity or sea scallop concentrations are known to occur to provide more precise estimates of relative abundance.

In contrast to the USA depth-based stratification scheme, the stratified design of the Canadian scallop surveys is based on geographic contours of commercial catch per unit of effort by the Canadian scallop fleet (Jamieson and Chandler 1980; Robert et al. 1982; Mohn et al. 1985). Prior to each annual survey, isopleth maps of Canadian CPUE values derived from the previous eleven months of fishing activity are generated. CPUE strata are established by grouping one-minute square (latitude and longitude) CPUE values into four categories (high, medium, low, and very low) and constructing closed curve contours of the geographical area subsumed within CPUE stratum. The CPUE levels (expressed as kg per crew member-hours fished-meter width of dredge [kg/crhm]) used in the 1982-1984 surveys were: <0.2, 0.2-0.5, 0.5-1.0, and >1.0. Survey sampling stations are allotted to the three lower CPUE strata in proportion to their relative area. The highest CPUE stratum is sampled much more heavily, with 40% of the annual survey stations allocated to this region (Robert and Jamieson 1984). Within strata, stations are randomly selected from an array of potential sampling locations spaced 2.2 km apart. Since the areal distribution of commercial catch rates changed from year to year, the area enclosed by each CPUE stratum (i.e., the "weighting factor" in a stratified estimate) varied among years.

The area covered in the 1982-1984 Canadian surveys of the Northern Edge and Peak region was slightly smaller (4,112 n mi^2) than in the USA surveys. Boundaries of the Canadian survey area ranged from 41°18' to 42°12'N latitude and from 65°48' to 67°30'W longitude. Depth sampled varied from 44-187 m (24-102 fm).

Sampling and Catch Processing Procedures

Nearly identical sampling and catch processing procedures were used in the 1982-1984 USA and Canadian surveys. The principal differences between the two surveys were in the duration and speed of the "standard tow" performed at each stratum. In the USA surveys, the survey dredge was towed for 15 minutes at 3.5 knots with a 3:1 wire scope. In the Canadian surveys, the survey dredge was hauled for 10 minutes at 4.0 knots with a 3:1 wire scope (Table 1). Hence, the mean tow distance per station was 0.875 nautical miles in the USA surveys vs 0.667 nautical miles in the Canadian surveys. In all other respects, the survey procedures were similar. After each tow the catch was sorted into biological and trash components. All live

scallops were enumerated and shell height measurements taken, by 5-mm interval, on all individuals. Occasionally, subsampling was necessary when large quantities of scallops were taken. All by-catch of finfish and other invertebrates were also enumerated and measured. Trash portions were measured by volume and substrate type and composition noted. The sampling dredge and liner were routinely inspected and repaired or replaced as appropriate. Hydrographic and navigational data were recorded at each sampling location including tow distance over bottom using a Doppler speed log (USA surveys only).

Data Analysis

Sea scallop relative abundance indices were calculated in terms of mean number per tow (both linear and ln (x+1)) and mean meat weight per tow[1] for each of the ten USA survey sampling strata comprising the Northern Edge and Peak region of Georges Bank (Figure 2), and in terms of stratified mean catch per tow (numbers and meat weight) for the entire Northern Edge and Peak region following the procedures of Cochran (1977: p. 91) and Pennington and Grosslein (1978). Survey indices were derived for pre-recruit scallops (<70 mm shell height), recruited or commercial-sized scallops (≥70 mm shell height), and total scallops (all sizes) per tow. Comparison of Canadian data with USA survey results was facilitated by post-stratifying Canadian sampling stations into USA sampling strata (Figure 3). The Canadian scallop catch data were then standardized into USA survey equivalents to account for the difference in mean tow distance between USA and Canadian standard survey tows (0.875 vs 0.667 n. mi). Standardization was accomplished by expanding the Canadian catch data from each tow by 1.312 (0.875/0.667). Mean catch per tow values from the standardized Canadian survey data were subsequently calculated for each USA sampling stratum and for the entire survey area. Size frequency data from both the USA and Canadian surveys were summarized by sampling strata and overall, and expressed as standardized mean number of scallops caught per shell height interval per tow.

Canadian tows located outside of the USA survey strata boundaries (i.e., >110 m) were excluded from all analyses. Equally, for those strata in which no Canadian survey tows occurred (Stratum 73 in 1982, 1983, and 1984; Stratum 72 in 1982 and 1983; Table 1 and Figure 3), no comparisons could be made with USA survey results. Hence, the USA data from these strata were also excluded from subsequent analyses.

Comparisons between the USA and Canadian estimates of relative scallop abundance for each stratum in each year were accomplished using a two-sample analysis of variance (student t-test). In several cases, the sample variances were heterogeneous and approximate t-tests (Sokal and Rohlf 1981: p. 411) were performed to test the equality of the USA and Canadian mean catch per tow values. Similar testing procedures were employed in comparing the mean depth sampled in each stratum between the two surveys. Differences in USA and Canadian shell height frequency distributions were evaluated, on a stratum and regional basis, using the Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981:p.443). Spatial patterns in scallop abundance and recruitment were inferred from differences in mean catch per tow indices and size frequency distributions among strata from both the USA and Canadian survey results.

RESULTS

Sampling Intensity and Overall Catch

A total of 814 tows from the USA and Canadian 1982-1984 Northern Edge and Peak scallop surveys were analyzed (235 tows, USA; 579 tows, Canada). Sampling in the three USA surveys averaged 78 tows per year (range:75-82); an average of 193 tows per year (range:165-225) was accomplished in the Canadian surveys (Table 1). Annual survey sampling intensity (tows per sq n mile) varied between 1:51 and 1:55 in the USA surveys and between 1:18 and 1:24 in the Canadian surveys (Table 2).

[1]Meat weight per tow values were derived by applying USA Georges Bank shell height-meat weight equation to survey shell height frequency distributions.

In all three years, the number of tows performed in the Canadian surveys was more than double that in the USA surveys. In 1983, Canadian sampling intensity was nearly 3X higher than for the USA (1:18 vs 1:51).

Individual stratum sampling intensities in the USA surveys ranged between 1:11 (Stratum 65 in 1983) and 1:126 (Stratum 72 in 1984), and between 1:9 (Stratum 64 in 1983; Stratum 71 in 1984) and 1:126 (Stratum 72 in 1984) in the Canadian surveys (Table 2). The largest difference in allotted sampling effort between the USA and Canadian surveys occurred in 1983 in Stratum 64 (Figure 3); Canada performed 110 tows in this stratum vs 14 tows by the USA (Table 1), about an eight-fold difference in sampling intensity. In all three years, more tows were accomplished in this stratum during the Canadian surveys than in any other.

Sea scallop catches ranged from 0 to 5,560 individuals per tow in the 1982-1984 USA surveys and from 0 to 8,428 standardized (6,424 unadjusted) scallops per tow in the Canadian surveys. Over all three years, the total number of scallops sampled was 208,284 (51,585 by USA; 156,699 by Canada) weighing 1.12 mt (meat weight). The largest single catches in the USA surveys occurred in Stratum 66 in 1982 and 1983 (1,243 and 1,433 scallops, respectively) and in Stratum 64 in 1984 (5,560 scallops). In all years, the highest individual Canadian survey catches were obtained from Stratum 64 (1,659 in 1982; 1,939 in 1983; and 8,428 in 1984).

Sampling Locations

Station (tow) locations sampled in the 1982-1984 USA and Canadian scallop surveys are depicted, within USA sampling strata, in Figure 3. Geographical overlap between the surveys was greatest in the northeastern sections of Georges Bank (Strata 63, 64 and 66). Canadian coverage of the more westerly and southwesterly regions of the Bank was more sporadic than in the USA surveys. Few Canadian stations occurred in the southern portions of Strata 61 and 62; no Canadian survey tows were performed in the western extensions of Strata 65, 66 and 71. At face value, these within-stratum differences in USA and Canadian spatial sampling distributions suggested that abundance indices from the two surveys would significantly differ due to the patchy nature of scallop distribution.

Relative Abundance Estimates

USA and Canadian relative abundance and biomass indices from the 1982-1984 sea scallop surveys are summarized in Tables 4 and 5. Virtually parallel estimates of stratified mean number and mean weight per tow for the entire Northern Edge and Peak region were obtained in each year. Percentage differences between the USA and Canadian regional abundance estimates were minor: 7% in 1982 (117.5 vs 110.0); 35% in 1983 (95.2 vs 128.2); and 5% in 1984 (347.8 vs 330.9). Percentage differences between annual USA and Canadian weight per tow indices were also modest: 8% in 1982 (1.18 vs 1.09); 34% in 1983 (0.82 vs 1.10) and 14% in 1984 (1.13 vs 0.99). USA and Canadian catch per tow estimates were also remarkably similar for pre-recruit scallops (<70 mm) and for recruited ($\geq$70 mm) scallops. The largest percentage difference in pre-recruit estimates was 22% in the 1983 surveys (54.4 vs 66.2 scallops/tow; 0.09 vs 0.11 kg/tow), while the largest difference in recruit catch per tow was 34% (0.73 vs 0.98 kg/tow in 1983).

On a stratum basis, only about 20% of the 150 paired USA/Canadian catch per tow estimates during 1982-1984 differed by as much as 100% (Table 3). In many of these cases, however, absolute differences in the indices were small (i.e., 0.04 vs 0.02 kg/tow or 9.7 vs 4.0 scallops/tow).

For the linear total number per tow abundance estimates (Table 4), coefficients of variation on a stratum basis were large ranging between 75 and 208% in the USA surveys and 33 and 336% in the Canadian surveys. Little consistency was apparent between sample size (number of tows) and the resultant coefficient of variation. For the overall Northern Edge and Peak region, annual coefficients of variation associated with the Canadian stratified linear abundance indices were 40-60% lower than those from the USA surveys. Over the three survey years, the mean coefficients of variation for the linear Northern Edge and Peak USA and Canadian number per tow estimates were 24.6% and 11.7%, respectively, indicating that proportional changes in abundance of less than about ±50% and ±25% would

normally not be detected with high probability (i.e., P = 0.05).

USA and Canadian ln (x+1) transformed abundance estimates exhibited much less variability than the corresponding linear values. Stratum coefficients of variation ranged between 20 and 124% in the USA surveys and between 6 and 142% in the Canadian surveys. Almost all of the transformed coefficients of variation were one-quarter to one-half as large as their respective linear values implying a significant improvement in relative precision using the transformation. On an absolute basis, however, there is little improvement in detecting proportional changes in abundance since retransformed confidence bands are about as large as the linear confidence intervals (~±50% for USA estimates; ±30% for Canadian estimates).

Pairwise comparisons of USA and Canadian stratum relative abundance estimates [linear and ln (x+1) mean number per tow] revealed that most pairs were not significantly different (Table 5). No statistical differences ($P > 0.05$) were detected between USA and Canadian mean catch per tow values for any stratum in the 1982 and 1984 surveys. In the 1983 survey, only the linear abundance estimates for Stratum 71 and the transformed abundance estimates for Strata 64, 66 and 71 were statistically significant ($P < 0.05$). Of these, only the USA and Canadian Stratum 71 ln (x+1) estimates were significantly different at the P=0.01 level. In none of the three years did USA and Canadian abundance estimates (linear or transformed) for the entire Northern Edge and Peak region differ statistically from one another ($P > 0.05$).

The similarity in USA and Canadian results implies that both surveys sampled the same populations of scallops in each year. As previously noted, however, the geographical distributions of USA and Canadian sampling stations within strata were not identical. To evaluate whether spatial differences in USA and Canadian tow locations resulted in different depths, within strata, being sampled, the mean depth per tow in the two survey series was compared (Table 5). In only three instances during the three years (Stratum 65 in 1982 and Strata 62 and 66 in 1984) were significant differences between the mean depth sampled in the USA and Canadian surveys detected ($0.01 < P < 0.05$). Yet in none of these strata were USA and Canadian abundance estimates significantly different. These results suggest that the spatial differences, per se, in the USA and Canadian survey tow locations were not a major source of variability affecting the comparability of USA and Canadian abundance estimates.

Size Frequency Distributions

USA and Canadian sea scallop size frequency distributions from the 1982-1984 surveys are presented by stratum in Figures 4-6. In nearly all cases, similar shell height frequency patterns are apparent in both the USA and Canadian size distributions. The frequency distributions indicate that both the USA and Canadian survey gears tend to effectively retain scallops after individuals have attained a size of 30-40 mm shell height (i.e., scallops in their third year of life). Incoming recruitment to the commercial fishery can thus be assessed from the survey data at least one to two years in advance.

The 1982 and 1983 data (Figures 4 and 5) show little sign of above-average recruitment (i.e., a prominent mode between 30-60 mm). Only the modal peaks at about 40 mm in Strata 62 (USA only), 64, and 65 in the 1983 surveys indicate incipient recruitment. In 1984, however, both USA and Canadian surveys caught large numbers of pre-recruit scallops in Strata 62, 63, 64, 65 and 66 (Figure 6) implying production of an outstanding 1981 year class. USA and Canadian 1984 pre-recruit abundance indices for the Northern Edge and Peak region (293.8 and 283.9, respectively: Table 3) were 4-7 fold higher than the corresponding 1982 and 1983 pre-recruit indices (Table 3 and Figure 7a). In both 1984 surveys, catch per tow indices of pre-recruit scallops in Stratum 64 were a magnitude higher than in the preceding two years (~1000 vs 100 scallops/tow). Examination of the 1982-1984 size frequency distributions and catch per tow estimates from both USA and Canadian surveys suggest that recruitment, and hence abundance of scallops, tends to be localized and greatest in the north-easterly portions of the Bank (Strata 64, 65 and 66).

Stratum comparisons of USA and Canadian shell height frequency distributions indicated statistically significant ($P < 0.05$) differences in

half of the 24 two-sample tests performed with the 1982-1984 survey data (Table 5). Differences were detected between USA and Canadian size distributions in three strata in 1982, four strata in 1983 and five strata in 1984. USA and Canadian results were statistically different in Strata 66 and 71 in all three years. Other differences in size frequencies were inconsistent over time, occurring in one year but not another. Moreover, the nature of the differences was not consistent. For example, for Stratum 66, the USA survey caught a higher proportion of smaller scallops than the Canadian survey in 1982 and 1983 but not in 1984 (Figures 4-6). Likewise, although USA and Canadian size frequency distributions differed in Stratum 65 in both 1982 and 1984, in the former year the cumulative frequency of small scallops in the USA survey accounted for the difference while in the latter year it was the Canadian catches of small scallops that resulted in the distribution being statistically significant. Since the Kolmogorov-Smirnov two-sample test (K-S test) used in testing the differences between the USA and Canadian frequency distributions only considers the largest differences between two frequency distributions (Sokal and Rohlf 1981), statistically significant differences can result which are not biologically meaningful. This is illustrated in Figure 7 in which the overall Northern Edge and Peak sea scallop size frequency and cumulative size frequency distributions are depicted from the 1982-1984 USA and Canadian surveys. The K-S test results for 1982 and 1983 indicated no significant difference between USA and Canadian frequency distributions but a highly significant difference ($P < 0.01$) between the two survey distributions in 1984. Visual scrutiny of the 1984 USA and Canadian frequency distributions (Figure 7a) shows prominent modes of about equal magnitude (representing the 1981 cohort) in both surveys but with the modal peaks about 10 mm apart (37 mm in Canadian survey; 47 mm in USA survey). For such young, rapid-growing scallops, the difference in modal peaks between the surveys has little, if any, biological meaning. Hence, although the 1984 USA and Canadian distributions differ statistically, this difference has limited external validity and pragmatically seems of little relevance.

DISCUSSION

Comparative analyses of USA and Canadian sea scallop data obtained in independent annual summer surveys of the Northern Edge and Peak region of Georges Bank during 1982-1984 indicate a high degree of concordance between the data sets. Statistically comparable estimates of relative abundance, recruitment levels, and size composition were obtained from both surveys in all three years. Since sampling design and sampling intensity differed between the two survey series, why should the results be so similar?

Several factors can be identified that may contribute to the concordance of results:

a) Survey design differences may be more apparent than real. Although stratification of the USA and Canadian surveys are based on different variables (depth vs commercial CPUE), neither survey uses strictly proportional sampling. In the USA survey, additional randomly selected sampling stations are frequently placed in strata for which prior information exists on fishing effort and/or scallop concentrations. In the Canadian survey, sampling intensity is extremely disproportionate with respect to stratum area. Presumed areas of greatest scallop abundance are sampled with extremely high intensity; in the 1983 Canadian scallop survey, 40% of the total sampling stations were assigned to the "high" CPUE strata which comprised only 12% of the total survey area (Robert and Jamieson 1984). As a consequence, the largest number of sampling tows in both surveys tend to be allotted over the same general geographical areas. The random assignment of tows within strata makes the distributional array of USA and Canadian sampling stations within these areas nearly similar (i.e., see station locations during 1982-1984 in Strata 63, 64 and the easterly portions of Strata 65 and 66: Figure 3). Resultingly, using similar survey gear, comparable indices of abundance and size composition are obtained from both surveys.

b) Variance differences in strata abundance estimates are not considered in survey designs. Neither the USA or Canadian survey designs are optimal in the sense of efficiently allocating sampling stations to reduce the variance in stratum catch rates. Strata

indices of variability (standard deviation and coefficient of variation) are relatively high in both surveys and exhibit a wide range among strata, within and between years. While differential catchability associated with bottom type and scallop density may be a cause of this variation, the variation is not addressed in the sampling designs of either surveys. Hence, the comparability of USA and Canadian survey results may reflect an imprecision in discriminating all but the most extreme differences in USA and Canadian mean catch per tow values (i.e., the 5-fold difference in the 1983 linear catch per tow values for Stratum 71: Table 5).

c) Historically low stock levels in 1982-1984 may have impeded the detection of differences in USA and Canadian survey results. Sea scallop abundance in the Northern Edge and Peak region during 1982-1984 was at a record-low level. Both USA and Canadian survey indices in these years were the lowest in their respective time series. Equally, both USA and Canadian commercial catch rates during the period reached their lowest levels ever. Given the depauperate condition of the scallop resource throughout the Northern Edge and Peak region, the likelihood that significantly different results could occur between the USA and Canadian surveys seems remote. Contrariwise, the increase in abundance of pre-recruit scallops in 1984 (i.e., the 1981 year class) was so large that both surveys would be expected, given a modicum of sampling intensity, to similarly detect this change.

d) Scallop patches remain in the same general geographical locality over time. Examination of spatial distributions of sea scallop concentrations from the extended time series of USA (1975-1984) and Canadian (1977-1984) surveys indicates that scallop patches (cohorts) "show up year after year in the same general location" (Robert et al. 1982), even though the patches are thinned down by the fishery. New patches arise from recruitment and existing patches become less distinct due to fishery removals. Success in sampling these patches is facilitated in the Canadian survey by stratifying on commercial catch per effort (CPUE) (a surrogate measure of patch distribution and density) derived from the fishery for a period up to eleven months before the survey. It is probable, however, that patches that produced high CPUE even a month or two prior to the survey will be of minor importance at the time the survey is conducted. Hence, the Canadian survey may be no more likely to sample extant patches of sea scallops than the USA survey in which sampling is based on preset stratum areas. Mean catch per tow values for the four CPUE strata sampled in the Canadian 1983 survey suggest that this is the case.The highest value was obtained from the "low" CPUE strata (172 scallops/tow), while the "high", "medium", and "very low" CPUE strata had catch per tow values of 112, 69 and 69, respectively (Mohn et al. 1985:p. 14). These findings imply that the correspondence between USA and Canadian survey indices results from similar probabilities in encountering scallop beds.

Irrespective of the factors actually responsible for the concordance of the USA and Canadian survey results, the informational content provided by the surveys appears to be the same. In this sense, the surveys are redundant. Since ship time involved with these surveys is costly, it might be prudent to consider alternate year coverage of the Georges Bank scallop resource by the USA and Canada. The present analyses indicate that there would be virtually no loss in accuracy or precision in sharing the survey responsibilities, and a considerable savings of expense would ensue to both countries.

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Table 1. Summary of USA and Canadian sea scallop research vessel survey cruises conducted in the Northern Edge and Peak region of Georges Bank, 1982-1984. For each survey, vessel, gear, tow duration, and tow speed data are provided as well as the number of tows accomplished in USA sea scallop survey sampling strata (Strata 61-66; 71-74).

Year	Month	Country	Research Vessel	Dredge Type	Average Tow Duration (min)	Average Tow Speed (knots)	Number of Tows Accomplished — USA Sea Scallop Sampling Stratum										Total Tows	Total[2] Tows Analyzed
							61	62	63	64	65	66	71	72	73	74		
1982	Jul	USA	ALBATROSS IV	2.44 m-lined	15	3.5	7	9	10	14	12	14	4	5	5	5	85	75
1982	Aug-Sep	CAN	E.E. PRINCE	2.44 m-lined	10	4.0	10	8	21	90	3	23	6	NS[1]	NS	4	165	165
1983	Aug	USA	ALBATROSS IV	2.44 m-lined	15	3.5	7	9	10	14	15	14	4	4	4	5	86	78
1983	Aug	CAN	E.E. PRINCE	2.44 m-lined	10	4.0	5	19	40	110	9	27	10	NS	NS	5	225	225
1984	Aug	USA	ALBATROSS IV	2.44 m-lined	15	3.5	7	9	10	14	14	14	5	4	4	5	86	82
1984	Aug	CAN	E.E. PRINCE	2.44 m-lined	10	4.0	9	18	29	56	12	25	17	4	NS	19	189	189

[1]NS = No tows performed.

[2]USA survey tows performed in strata in which no Canadian survey tows were performed were excluded from subsequent comparative analyses.

Table 2. USA and Canadian sea scallop research vessel survey sampling intensity (number of tows accomplished per square nautical mile) for tows performed in USA sea scallop strata in the Northern Edge and Peak region of Georges Bank, by stratum and year, 1982-1984.

Stratum Number[1]	Area (n. mi^2)	Depth Range m	Depth Range fm	Survey Sampling Intensity(tows per n. mi^2) 1982 USA	1982 CAN	1983 USA	1983 CAN	1984 USA	1984 CAN
61	576	55-73	30-40	1:82	1:58	1:82	1:115	1:82	1:64
62	701	73-110	40-60	1:78	1:88	1:78	1:37	1:78	1:39
63	694	55-73	30-40	1:69	1:33	1:69	1:17	1:69	1:24
64	988	73-110	40-60	1:71	1:11	1:71	1:9	1:71	1:18
65	164	55-73	30-40	1:14	1:55	1:11	1:18	1:12	1:14
66	266	73-110	40-60	1:19	1:12	1:19	1:10	1:19	1:11
71	146	46-55	25-30	1:37	1:24	1:37	1:15	1:29	1:9
72	504	27-46	15-25	EXC[2]	NS[3]	EXC[2]	NS[3]	1:126	1:126
74	433	46-55	25-30	1:87	1:108	1:87	1:87	1:87	1:23
Total	4472	27-110	15-60	-	-	-	-	1:55	1:24
	(3968)[4]	46-110	25-60	1:53	1:24	1:51	1:18	-	-

[1]Data from stratum 73 have been excluded. Although the USA survey sampled this stratum in each year, no Canadian tows were performed in this stratum in any year. Hence, comparative data between the surveys do not exist.

[2]EXC = USA tow data exist but have been excluded since no comparative Canadian survey tows were performed.

[3]NS = No survey tows were performed.

[4]In 1982 and 1983, no Canadian tows were performed in Stratum 72. Hence, the total area of the strata in which corresponding USA and Canadian tows were performed was 3968 n. mi^2.

Table 3. USA and Canadian sea scallop research vessel survey relative abundance indices (standardized mean number and mean weight per tow) (meats only, kg) and mean shell height (mm) of sea scallops from the Northern Edge and Peak region of Georges Bank, by sampling stratum, 1982-1984. Survey indices are presented for pre-recruit (<70 mm shell height), recruit (≥70 mm shell height), and total scallops per tow. Abundance indices for the entire Northern Edge and Peak region represent stratified means.

Year / Stratum	Number of Tows		Mean Number of Scallops Per Tow						Mean Meat Weight(kg) of Scallops Per Tow[1]						Mean Shell Height	
			Total		<70 mm		≥70 mm		Total		<70 mm		≥70 mm			
	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada
1982																
61	7	10	11.4	7.1	0.1	0.0	11.3	7.1	0.40	0.34	<0.01	0.00	0.40	0.34	121.3	136.8
62	9	8	66.2	64.6	7.9	5.8	58.3	58.8	0.95	0.86	0.03	0.02	0.92	0.84	90.6	89.7
63	10	21	63.0	99.5	37.5	42.0	25.5	57.5	0.56	1.04	0.11	0.13	0.45	0.91	74.1	79.8
64	14	90	237.5	204.0	78.1	81.9	159.4	122.1	2.37	1.79	0.21	0.24	2.16	1.55	78.9	75.5
65	12	3	236.4	141.3	122.3	25.0	114.1	116.3	1.63	1.43	0.34	0.08	1.29	1.35	69.9	81.8
66	14	23	297.8	269.6	167.1	107.8	130.7	161.8	2.20	2.20	0.54	0.41	1.66	1.79	70.9	75.7
71	4	6	86.3	146.7	24.3	70.7	62.1	76.0	0.95	1.38	0.05	0.20	0.90	1.18	80.8	76.3
74	5	4	10.2	0.0	2.8	0.0	7.4	0.0	0.16	0.00	0.01	0.00	0.15	0.00	87.7	-
No. Edge & Peak	75	165	117.5	110.0	44.9	39.6	72.6	70.4	1.18	1.09	0.13	0.13	1.05	0.96	78.2	78.6
1983																
61	7	5	11.0	4.0	1.3	0.0	9.7	4.0	0.35	0.24	<0.01	0.00	0.35	0.24	115.1	148.0
62	9	19	105.0	64.4	60.4	29.2	44.6	35.2	0.87	0.85	0.06	0.03	0.81	0.82	64.4	79.3
63	10	40	39.6	66.9	14.1	36.8	25.5	30.1	0.51	0.63	0.04	0.09	0.47	0.54	84.8	73.4
64	14	110	156.4	221.3	94.1	113.5	62.3	107.8	1.31	1.71	0.16	0.17	1.15	1.54	67.8	67.3
65	15	9	245.0	444.6	197.3	375.7	47.7	68.9	1.11	1.74	0.36	0.61	0.75	1.13	57.3	54.7
66	14	27	219.9	312.8	114.3	96.5	105.6	216.3	1.50	2.63	0.11	0.15	1.39	2.48	62.3	73.4
71	4	10	32.3	168.9	14.8	100.0	17.6	68.9	0.55	1.22	0.03	0.21	0.52	1.01	85.0	68.1
74	5	5	29.0	35.6	11.2	6.6	17.8	29.0	0.31	0.77	0.04	0.02	0.27	0.75	81.6	101.0
No. Edge & Peak	78	225	95.2	128.2	54.4	66.2	40.8	62.0	0.82	1.10	0.09	0.11	0.73	0.98	67.9	69.5
1984																
61	7	9	18.3	5.2	5.3	0.2	13.0	5.0	0.53	0.29	0.01	<0.01	0.52	0.29	105.2	142.2
62	9	18	105.1	128.4	75.2	89.2	29.9	39.2	0.67	0.65	0.08	0.10	0.59	0.55	56.5	54.9
63	10	29	39.4	72.9	22.2	61.8	17.2	11.1	0.42	0.29	0.06	0.11	0.36	0.18	75.0	55.5
64	14	56	1297.3	1149.0	1165.9	1041.4	131.4	107.6	2.89	2.57	1.07	1.29	1.82	1.28	42.7	46.2
65	14	12	301.4	506.1	179.8	341.3	121.6	164.8	1.55	2.09	0.34	0.51	1.21	1.58	61.9	57.6
66	14	25	332.9	366.0	211.0	269.8	121.9	96.2	1.83	1.54	0.33	0.36	1.50	1.18	59.7	54.3
71	5	17	46.8	79.6	13.6	49.0	33.2	30.6	0.64	0.49	0.03	0.08	0.61	0.41	84.6	63.9
72	4	4	15.3	12.3	0.3	0.3	15.0	12.0	0.37	0.27	<0.01	<0.01	0.37	0.27	105.9	105.5
74	5	19	22.4	6.9	7.4	0.4	15.0	6.5	0.31	0.22	0.02	<0.01	0.29	0.22	85.5	117.1
No. Edge & Peak	82	189	347.8	330.9	293.8	283.9	54.0	47.0	1.13	0.99	0.30	0.36	0.83	0.63	46.7	48.9

[1]Mean meat weight derived by applying the USA Georges Bank research survey sea scallop shell height-meat weight equation,

ln Meat Weight (g) = -11.7656 + 3.1693 ln Shell Height (mm) (n = 5863, r = 0.98)

to each shell height in the survey frequency distribution, multiplying by the frequency at height, summing the products, and dividing by the total number of scallops in the frequency distribution.

Table 4. Standardized mean catch (number) per tow of sea scallops from USA and Canadian sea scallop research vessel surveys in the Northern Edge and Peak region of Georges Bank, 1982-1984. Standard deviation of the mean (S.D.), and the coefficient of variation (C.V.:100 S.D./Mean) are provided as indices of variability. Data are summarized by USA survey sampling strata and for the entire Northern Edge and Peak region [1].

Year / Stratum	Number of Tows		Linear						Ln (X+1)					
			Mean		S.D.		C.V.		Mean		S.D.		C.V.	
	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada	USA	Canada
1982														
61	7	10	11.4	7.1	11.8	9.2	103.5	130.2	2.0779	1.2857	1.1415	1.4002	54.9	108.9
62	9	8	66.2	64.6	65.4	78.4	98.8	121.3	3.8556	3.7731	0.8762	0.9253	22.7	24.5
63	10	21	63.0	99.5	126.9	195.0	201.4	195.9	1.8857	2.6553	2.2210	2.3309	117.8	87.8
64	14	90	237.5	204.0	282.4	285.6	118.9	140.0	4.5840	4.5152	1.7007	1.4820	37.1	32.8
65	12	3	236.4	141.3	351.5	97.0	148.7	68.6	4.2907	4.8117	1.7006	0.6488	39.6	13.5
66	14	23	297.8	269.6	397.3	358.0	133.4	132.8	4.5125	4.7586	1.9748	1.6781	43.8	35.3
71	4	6	86.3	146.7	77.4	48.0	89.8	32.7	3.4752	4.9563	2.3729	0.2950	68.6	6.0
74	5	4	10.2	0.0	17.9	0.0	175.7	-	1.4325	0.0000	1.5562	0.0000	108.6	-
No. Edge & Peak	75	165	117.5	110.0	22.1	12.9	18.8	11.7	3.2180	3.1421	0.2093	0.1331	6.5	4.2
1983														
61	7	5	11.0	4.0	14.0	2.7	127.2	68.5	1.7122	1.4780	1.4566	0.5901	85.1	39.9
62	9	19	105.0	64.4	149.7	46.6	142.6	72.4	3.8150	3.8498	1.5874	0.9243	41.6	24.0
63	10	40	39.6	66.9	58.1	118.9	146.7	177.9	2.0154	2.6798	2.1933	1.9391	108.8	72.4
64	14	110	156.4	221.3	271.5	281.7	173.6	127.3	3.9442	4.7797	1.6817	1.2701	42.6	26.6
65	15	9	245.0	444.6	257.9	440.6	105.2	99.1	4.3847	5.6184	2.0540	1.0667	46.8	19.0
66	14	27	219.9	312.8	412.2	365.4	187.5	116.8	3.5713	5.1432	2.1272	1.2614	59.6	24.5
71	4	10	32.3	168.9	33.9	175.1	105.0	103.7	2.9854	4.8299	1.2458	0.7631	41.7	15.8
74	5	5	29.0	35.6	60.4	30.7	208.3	86.2	1.6292	2.8609	2.0116	1.7941	123.5	62.7
No. Edge & Peak	78	225	95.2	128.2	22.1	11.2	23.2	8.7	2.9653	3.6204	0.2334	0.1220	7.9	3.4
1984														
61	7	9	18.3	5.2	23.0	6.2	126.0	119.1	2.3128	1.3080	1.2637	1.1525	54.6	88.1
62	9	18	105.1	128.4	105.8	118.0	100.7	91.8	4.3243	4.5802	0.8582	0.7560	19.8	16.5
63	10	29	39.4	72.9	64.3	245.1	163.1	336.4	1.8574	1.5151	2.2049	2.1529	118.7	142.1
64	14	56	1297.3	1149.0	1858.5	1587.1	143.3	138.1	5.7073	5.8225	2.3960	2.1463	42.0	36.9
65	14	12	301.4	506.1	398.9	810.8	132.4	160.2	4.2773	5.5941	2.1716	1.0332	50.8	18.5
66	14	25	332.9	366.0	621.0	446.2	186.5	121.9	4.4352	4.6963	1.7530	2.2415	39.5	47.7
71	5	17	46.8	79.6	35.0	115.0	74.9	144.3	3.1962	3.5815	1.1417	1.4289	35.7	39.9
72	4	4	15.3	12.3	13.4	8.0	87.5	65.4	2.5065	2.2884	0.8852	1.0753	35.3	47.0
74	5	19	22.4	6.9	40.7	8.4	181.6	121.5	1.6275	1.4204	2.0205	1.2399	124.1	87.3
No. Edge & Peak	82	189	347.8	330.9	110.5	48.7	31.8	14.7	3.4900	3.4048	0.2227	0.1284	6.4	3.8

[1]Catch per tow and standard deviation values for the entire Northern Edge and Peak region are stratified values, "weighted" by stratum area.

Table 5. Results of two-sample analyses of variance (student's t-test) comparing the linear mean number of sea scallops caught per tow, the ln (x+1) mean number of sea scallops caught per tow, and the mean depth sampled per tow, by USA sea scallop survey sampling stratum, in USA and Canadian sea scallop research vessel surveys conducted on the Northern Edge and Peak of Georges Bank, 1982-1984. Kolmogorov-Smirnov (K-S) two-sample test results are also presented comparing sea scallop height frequency distributions, by sampling stratum, from the USA and Canadian sea scallop surveys.

Stratum Number	Mean No. Per Tow		Student "t" Statistics		Ln(x+1) Mean No. Per Tow		Student "t" Statistics		Mean Depth(fm) Per Tow		Student "t" Statistics		K-S Test on Frequency Distributions	
	USA	CAN	t_s[1]	$t_{.05}$	USA	CAN	t_s[1]	$t_{.05}$	USA	CAN	t_s[1]	$t_{.05}$	D[2]	$D_{.05}$[2]
1982 USA and Canadian Survey Results														
61	11.43	7.10	0.85	2.13	2.078	1.286	1.23	2.13	36.0	36.8	0.57	2.13	0.34	0.65
62	66.22	64.63	0.05	2.13	3.856	3.773	0.19	2.13	46.7	48.8	1.06	2.13	0.12	0.24
63	63.00	99.52	0.54	2.05	1.886	2.655	0.87	2.05	35.4	36.2	0.67	2.05	0.20	0.22
64	237.50	204.04	0.41	2.00	4.584	4.515	0.16	2.00	45.6	47.4	1.29	2.00	0.12	0.13
65	236.42	141.33	0.45	2.16	4.291	4.812	0.51	2.16	31.9	37.3	2.37*	2.16	0.35**	0.14
66	297.79	269.57	0.22	2.04	4.513	4.759	0.40	2.04	44.4	46.6	1.09	2.02	0.17**	0.11
71	86.25	146.67	1.54	2.31	3.475	4.956	1.24[a]	3.16[a]	26.5	25.4	1.82	2.31	0.20*	0.18
74	10.20	0.00	1.27[a]	2.78[a]	1.433	0.000	2.06[a]	2.78[a]	26.8	28.5	1.37	2.37	N/A	N/A
1983 USA and Canadian Survey Results														
61	11.00	4.00	1.29[a]	2.46[a]	1.712	1.478	0.34	2.23	37.3	37.6	0.28	2.23	0.70	0.79
62	105.00	64.42	0.80[a]	2.30[a]	3.815	3.850	0.07	1.09	47.8	47.4	0.21	1.09	0.31**	0.21
63	39.60	66.85	1.04[a]	2.14[a]	2.015	2.680	0.94	2.00	36.8	36.7	0.11	2.00	0.25	0.27
64	156.43	221.31	0.81	1.98	3.944	4.780	2.23*	1.98	45.4	47.3	1.75	1.98	0.10	0.14
65	245.00	444.56	1.41	2.07	4.385	5.618	1.66[a*]	2.07	35.2	34.6	0.55	2.07	0.10	0.11
66	219.86	312.78	0.74[a*]	2.02	3.571	5.143	2.54[a*]	2.14[a]	48.4	48.1	0.12	2.14	0.26**	0.12
71	32.25	168.90	2.36[a*]	2.34[a]	2.985	4.830	3.43**	2.18	28.0	26.4	2.07	2.18	0.26*	0.26
74	29.00	35.60	0.22	2.31	1.629	2.861	1.02	2.31	30.6	30.0	0.34	2.31	0.41**	0.34
1984 USA and Canadian Survey Results														
61	18.29	5.22	1.46[a]	2.44[a]	2.313	1.308	1.66	2.15	38.4	38.3	0.07	2.15	0.49	0.67
62	105.11	128.44	0.50	2.01	4.324	4.580	0.79	2.01	47.6	50.7	2.76*	2.01	0.08	0.18
63	39.40	72.86	0.67[a]	2.08[a]	1.857	1.515	0.43	2.02	36.3	36.0	0.26	2.02	0.47**	0.27
64	1297.29	1148.96	0.30	2.00	5.707	5.823	0.18	1.98	47.8	48.1	0.22	1.98	0.31**	0.06
65	301.36	506.08	0.80[a]	2.19[a]	4.277	5.594	2.02[a]	2.17[a]	34.0	32.2	1.60[a*]	2.06	0.19**	0.10
66	332.93	366.04	0.19	2.02	4.435	4.696	0.38	2.02	46.7	50.1	2.31[a*]	2.09[a]	0.15**	0.10
71	46.80	79.65	1.03[a]	2.28[a]	3.196	3.582	0.50	2.09	27.2	26.7	0.41	2.09	0.34**	0.25
72	15.25	12.25	2.45	2.45	2.507	2.288	0.31	2.45	22.8	24.3	0.46	2.45	0.22	0.52
74	22.40	6.95	0.84[a]	2.77[a]	1.628	1.420	0.29	2.07	31.6	30.4	0.98	2.07	0.58	0.59

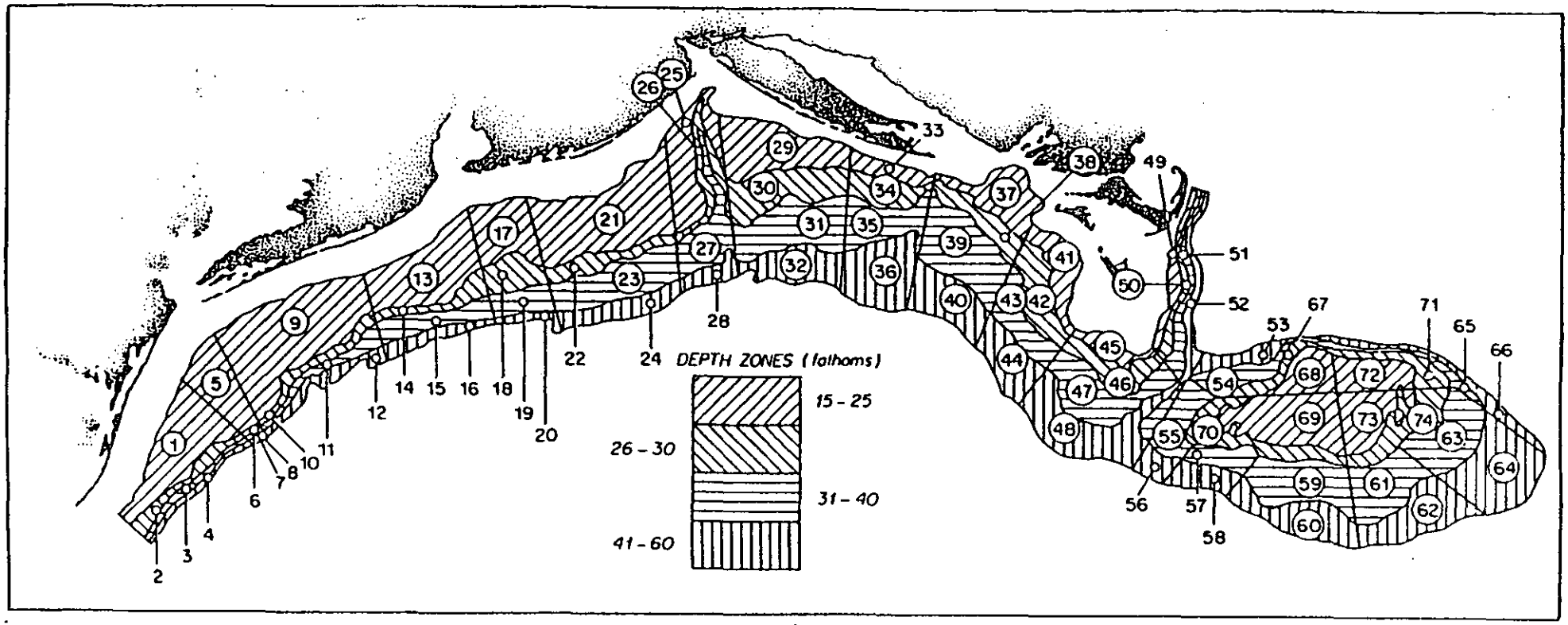
[1] $t_s = (\bar{Y}_1 - \bar{Y}_2) - (u_1 - u_2) \Big/ \sqrt{\left[\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1+n_2-2}\right]\left(\frac{n_1+n_2}{n_1 n_2}\right)}$ Sokal and Rohlf (1981:p. 226)

[2] $D = \left|\frac{F_1}{n_1} - \frac{F_2}{n_2}\right|$; $D_{.05} = K_{.05}\sqrt{\frac{n_1+n_2}{n_1 n_2}}$; $K_{.05} = \sqrt{\tfrac{1}{2}\left[-\ln\left(\frac{.05}{2}\right)\right]}$ Sokal and Rohlf (1981:p.443)

[a] Approximate t-test performed since F-test results indicated samples variances to be heterogeneous (see Sokal and Rohlf 1981:p. 411).

* $p < 0.05$.
** $p < 0.01$.

Figure 1. USA (Northeast Fisheries Center) sea scallop research vessel survey sampling strata in the Northwest Atlantic, Georges Bank to Cape Hatteras, used in annual surveys since 1979. For analytical purposes, survey strata are grouped by major fishing regions: Virginia-North Carolina (Strata 1-8); Delmarva (Strata 9-20); New York Bight (Strata 21-36); Southern New England (Strata 37-44); South Channel (Strata 45-56); Southeast Part (Strata 57-60); and Northern Edge and Peak (Strata 61-66, 71-74).



Strata No.	Square Miles	Strata No.	Square Miles	Strata No.	Square Miles	Strata No.	Square Miles
1	1163	20	120	39	967	57	184
2	175	21	1650	40	513	58	300
3	126	22	312	41	602	59	538
4	117	23	714	42	343	60	816
5	453	24	476	43	432	61	576
6	62	25	648	44	383	62	701
7	46	26	188	45	392	63	694
8	74	27	451	46	416	64	988
9	2171	28	149	47	871	65	164
10	152	29	1096	48	1109	66	266
11	229	30	669	49	244	67	210
12	204	31	932	50	150	68	370
13	1127	32	627	51	139	69	938
14	219	33	363	52	307	70	520
15	394	34	203	53	268	71	146
16	211	35	601	54	278	72	504
17	749	36	694	55	364	73	501
18	249	37	672	56	209	74	433
19	274	38	280				

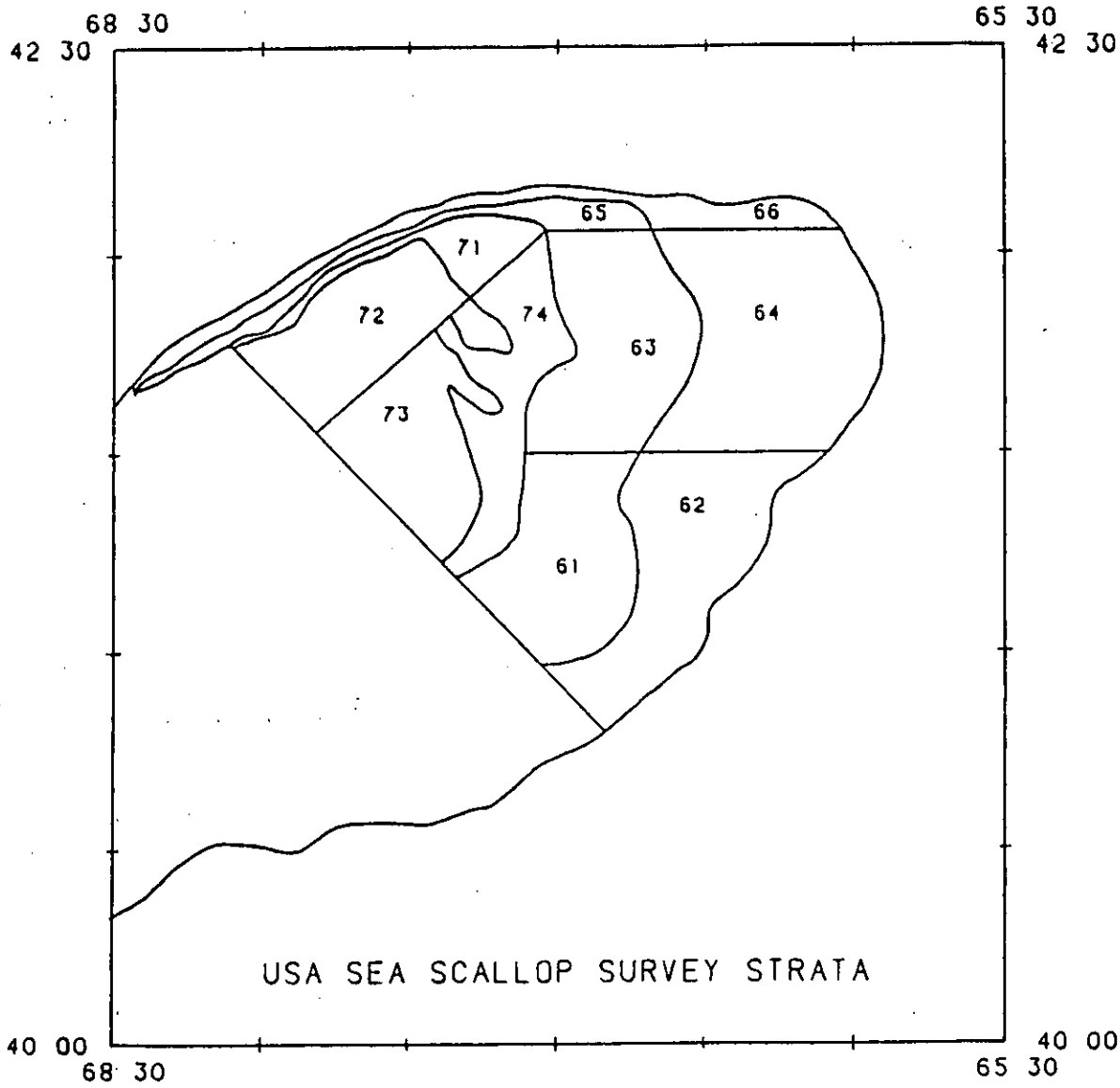


Figure 2. USA (Northeast Fisheries Center) sea scallop research vessel sampling strata in the Northern Edge and Peak region of Georges Bank used in annual surveys since 1979. The 10 sampling strata (61-66; 71-74) cover four depth zones (27-46 m: Strata 72 and 73; 46-55 m: Strata 71 and 74; 55-73 m: Strata 61, 63 and 65; 73-110 m: Strata 62,64 and 66) and encompass a total area of 4,472 square nautical miles.

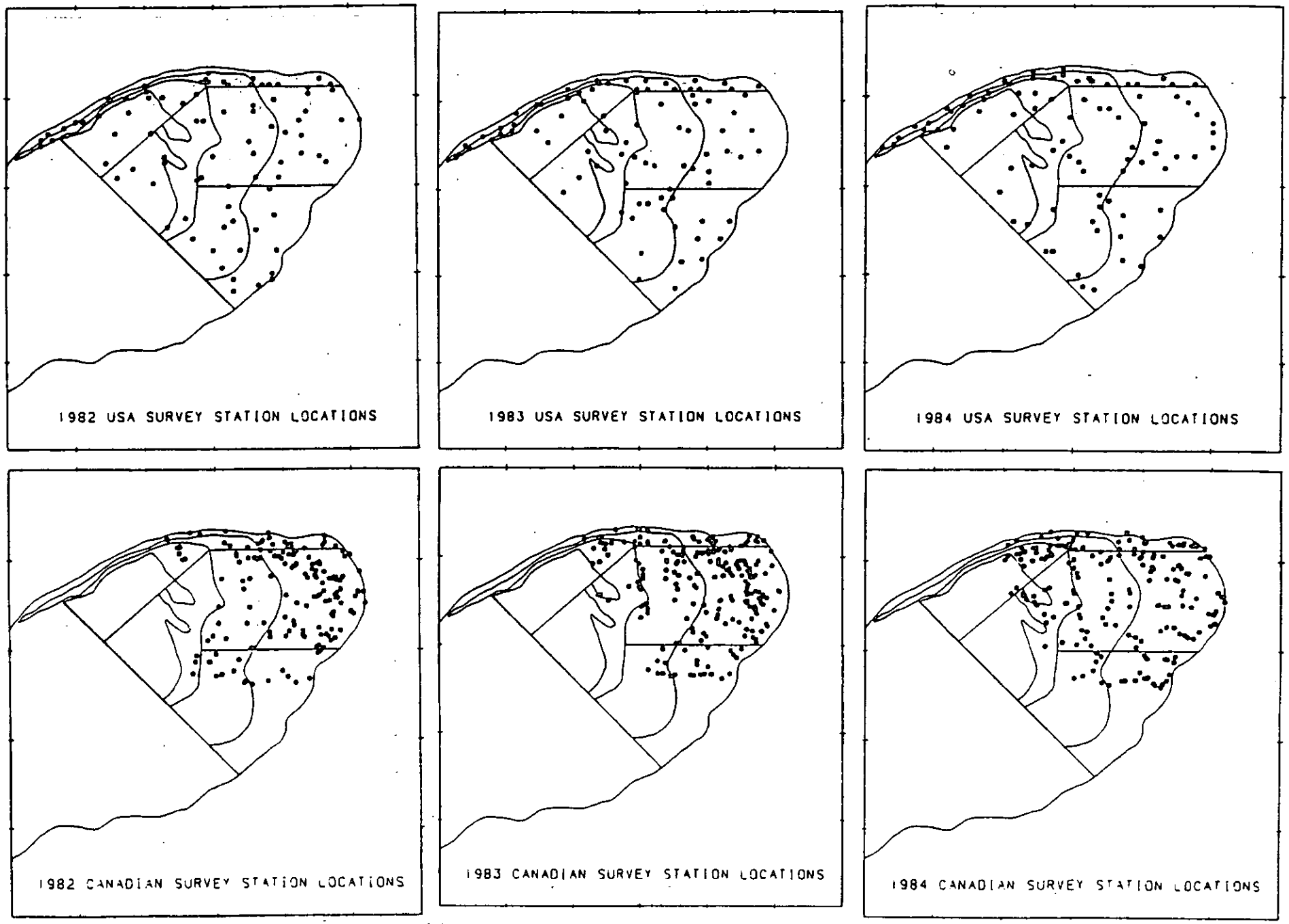


Figure 3. Station (tow) locations sampled in USA and Canadian sea scallop research vessel surveys in the Northern Edge and Peak region of Georges Bank, 1982-1984. Canadian survey locations outside of the USA sampling strata boundaries (ie, >110 m) are not depicted.

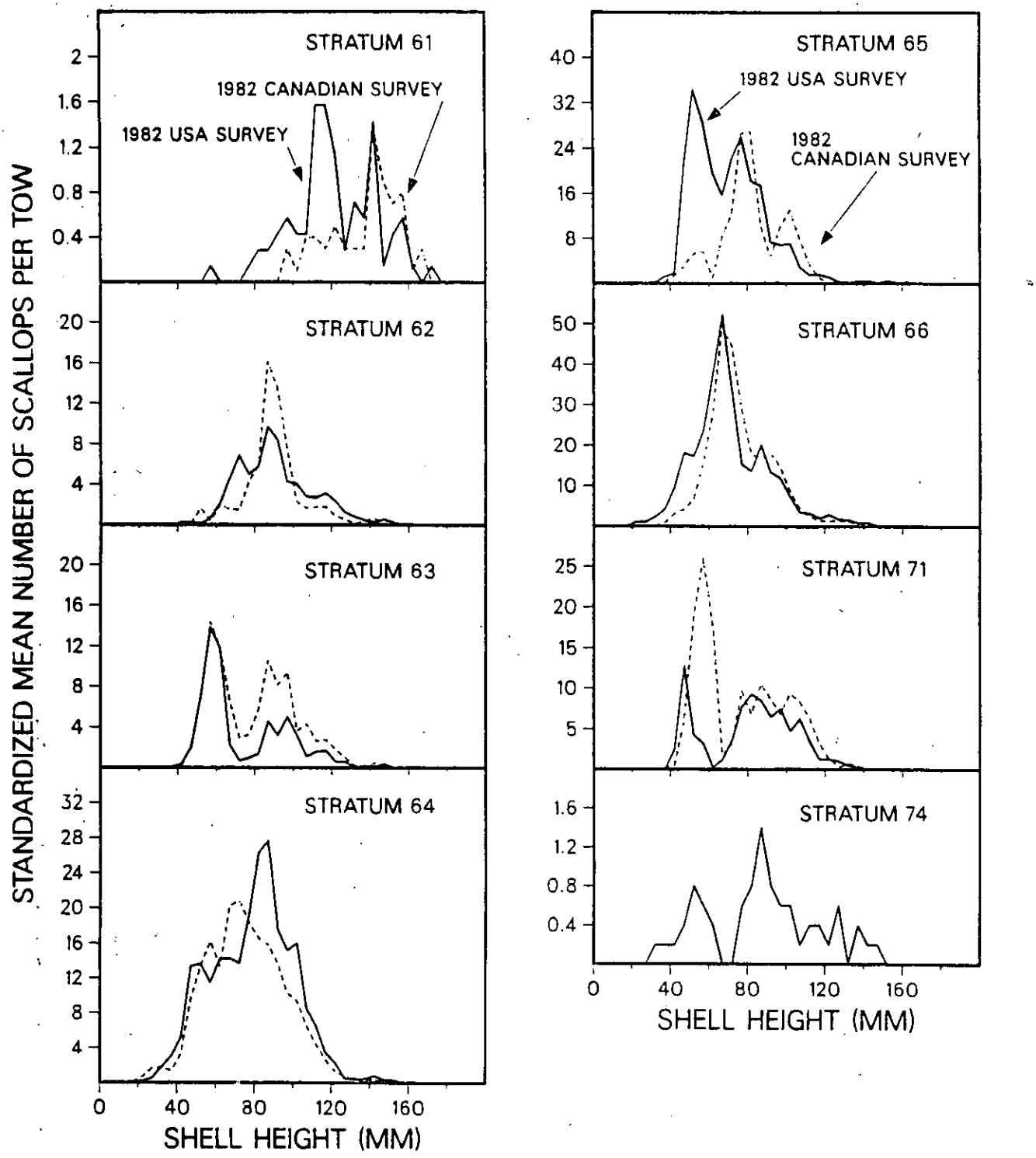


Figure 4. Comparison of 1982 USA and Canadian sea scallop research vessel survey shell height frequency distributions of sea scallops from the Northern Edge and Peak region of Georges Bank, by individual stratum. Canadian data were standardized to USA tow distance equivalents.

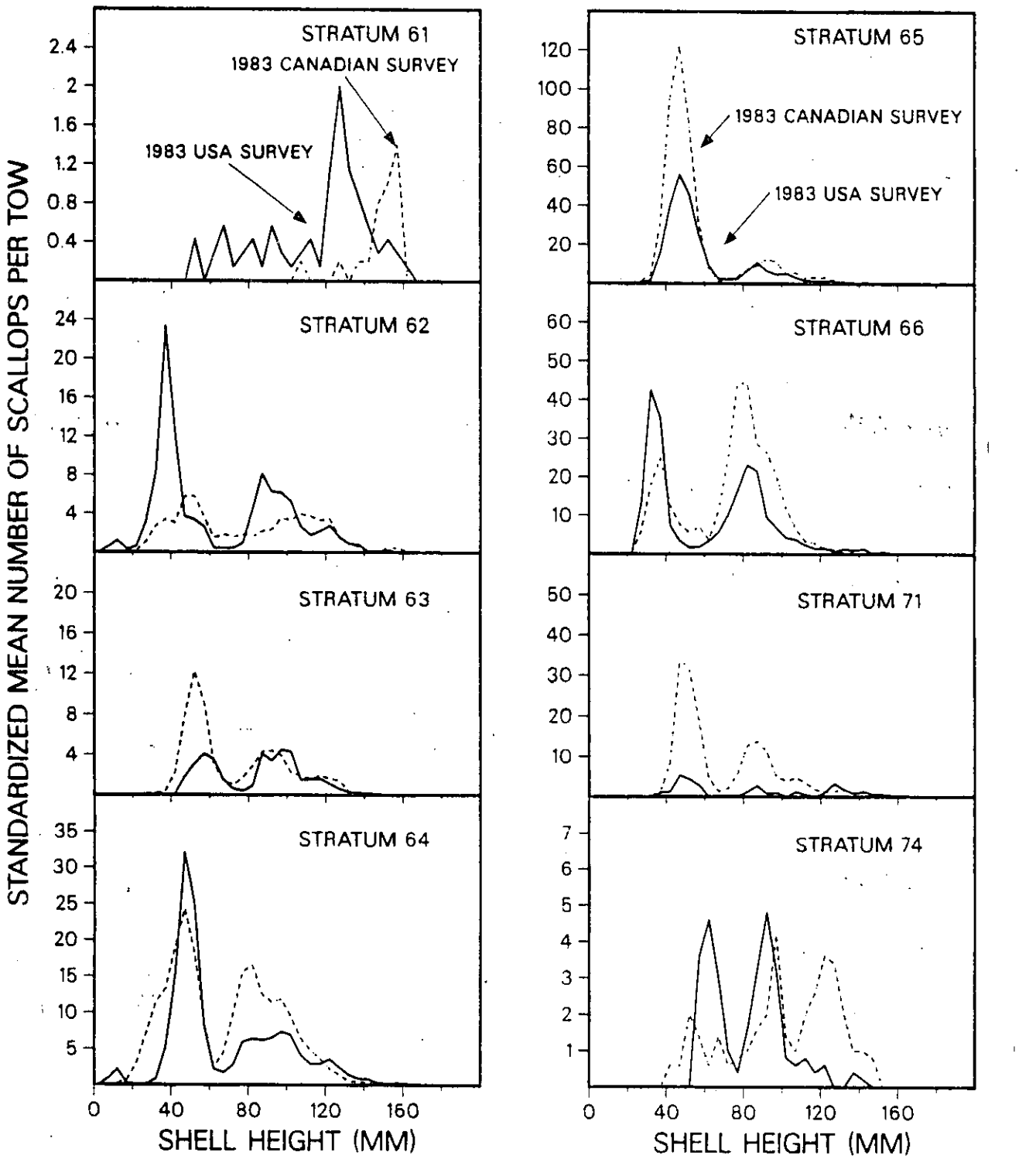


Figure 5. Comparison of 1983 USA and Canadian sea scallop research vessel survey shell height frequency distributions of sea scallops from the Northern Edge and Peak region of Georges Bank, by individual stratum. Canadian data were standardized to USA tow distance equivalents.

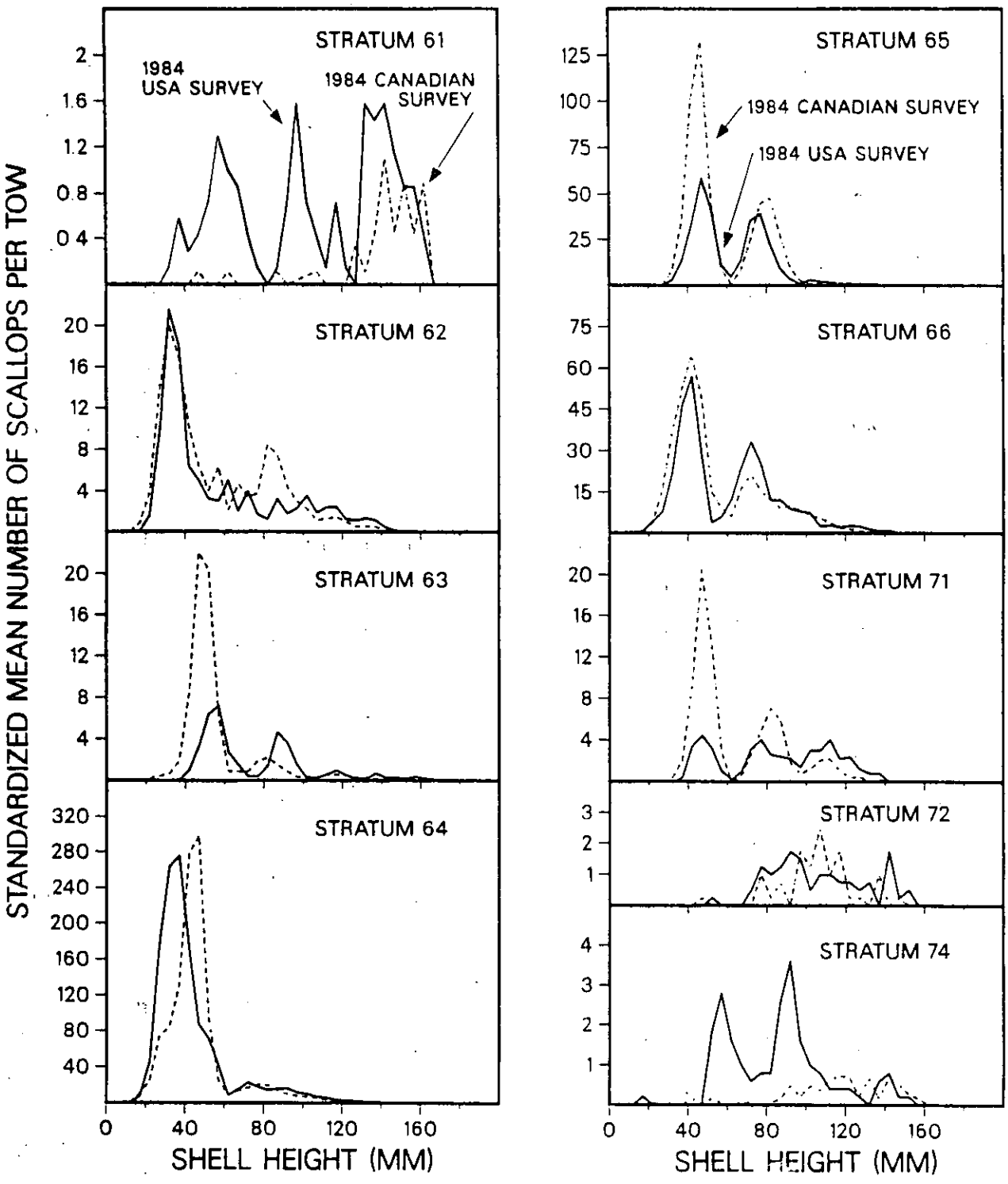


Figure 6. Comparison of 1984 USA and Canadian sea scallop research vessel survey shell height frequency distributions of sea scallops from the Northern Edge and Peak region of Georges Bank, by individual stratum. Canadian data were standardized to USA tow distance equivalents.

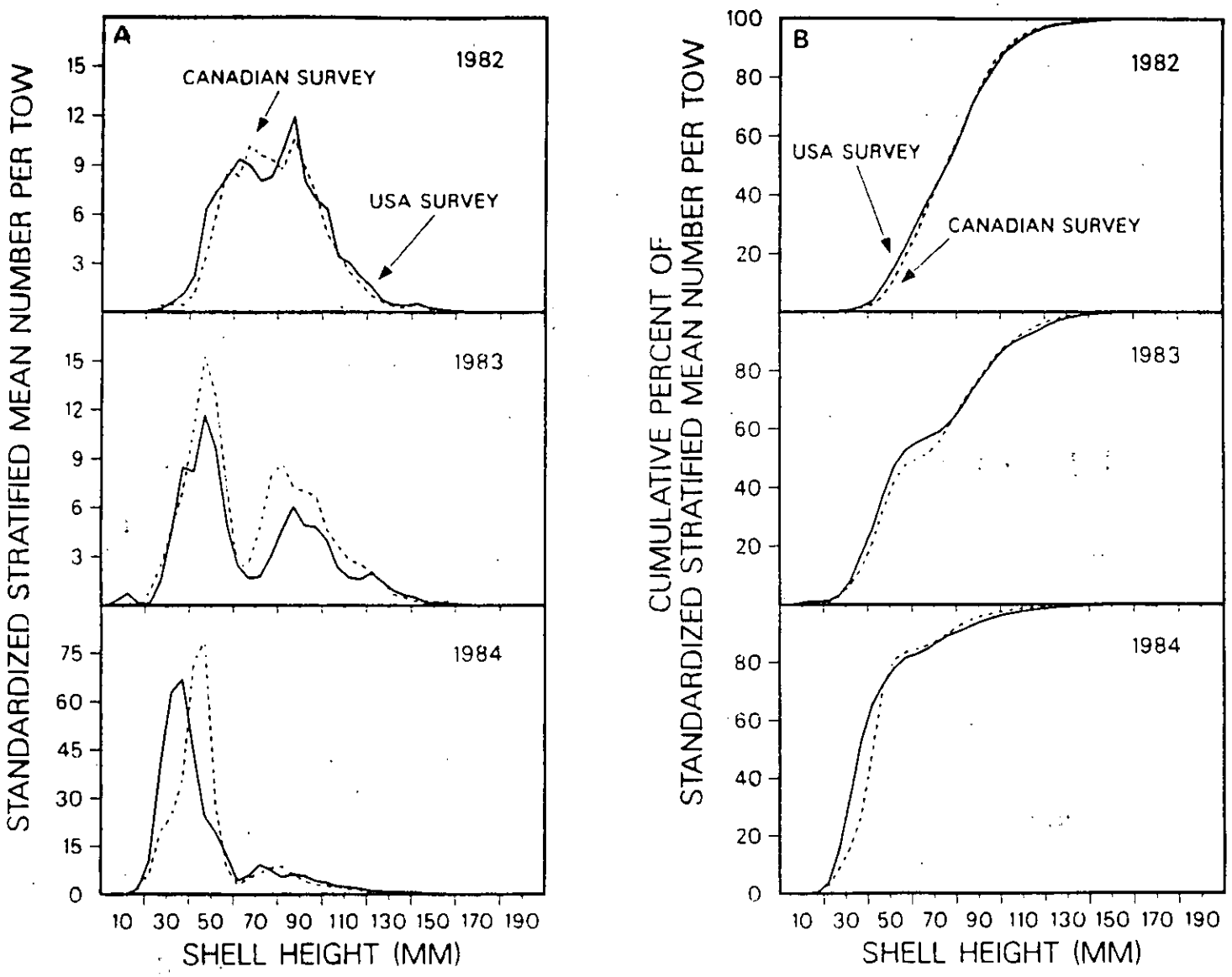


Figure 7. (A) Comparison of USA and Canadian sea scallop research vessel survey shell height frequency distributions of sea scallops from the Northern Edge and Peak region of Georges Bank, 1982-1984. In 1982 and 1983, data were derived from strata 61-66, 71 and 74. In 1984, data were derived from Strata 61-66, 71-72 and 74. Canadian data were standardized to USA tow distance equivalents and post-stratified into USA sampling strata.

(B) Comparison of USA and Canadian sea scallop research vessel survey cumulative percent shell height frequency distributions of sea scallops from the Northern Edge and Peak region of Georges Bank, 1982-1984.