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Juvenile Fish Surveys on the Scotian Shelf: Implications for Year-class Size Assessments

by

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SPECIAL SESSION ON BIOLOGICAL SURVEYS

Abstract

The utility of juvenile fish surveys for obtaining year class strength estimates is discussed, using data collected during midwater trawl surveys in the Northwest Atlantic for cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), silver hake (*Merluccius bilinearis*), and herring (*Clupea harengus*). Problems encountered in the development of juvenile fish abundance estimators included changes in availability to survey gear caused by diel or ontogenetic vertical migrations. Aspects of the vertical and geographical distribution of the four species presented here illustrate the need for careful, species-specific survey design based on adequate knowledge of juvenile fish behaviour. For example, a change in methodology of a juvenile silver hake survey on the Scotian Shelf predicated on the results of a study of diel distribution was associated with an increase in the precision of the abundance estimates. While the use of midwater trawl surveys for abundance estimates must be approached with caution, their use in general biological studies of distribution, behaviour, and even stock structure is advocated. In fact, such preliminary investigations are prerequisite to their practical application in juvenile abundance estimation.

Introduction

The utility of post-metamorphosis juvenile fish (0-group) surveys for determining year class strength of both gadoids and clupeoids has long been recognized in the eastern North Atlantic where annual surveys have been conducted in the Barent's and North Seas since 1965 and 1976 respectively (Anon., 1981; Hislop et al., 1981). These surveys are intended to provide abundance indices for several species concurrently, using a single methodology. This approach has had mixed success, with abundance estimates correlating well with independent estimates for some species, but not for others (Heessen et al., 1982). The value of continuing the North Sea 0-group surveys has been questioned recently (J. Hislop, pers. comm.).

Such problems are not confined to pelagic 0-group surveys. For example, on the Scotian Shelf, results from depth-stratified bottom trawl surveys are used for assessment of haddock (*Melanogrammus aeglefinus*) and Atlantic cod stocks (*Gadus morhua*), but are too variable for other commercially important stocks such as silver hake (*Merluccius bilinearis*), redfish (*Sebastes marinus*), and pollock (*Pollachius virens*) (Halliday and Koeller, 1981). Assuming that these mixed results are due mainly to differences in distribution and behaviour among species, it follows that additional complications during the pelagic phase of juvenile fish, such as different residence times and diel migrations in the water column, further reduce the feasibility of multipurpose midwater trawl surveys. To assess whether such surveys can provide valid abundance estimates for juvenile fish populations in the Northwest Atlantic, we examined midwater trawl survey data collected on the Scotian Shelf, for juvenile Atlantic cod, haddock, silver hake, and Atlantic herring (*Clupea harengus*). We have restricted our examination to these species as they represent a spectrum of life histories among commercially important species ranging from predominantly demersal (haddock) to pelagic (herring). Although we emphasize the problems, and in some cases the impracticality of using midwater trawl surveys for abundance estimation, we also point out their potential for studies of fish biology including stock structure, larval drift, and location of spawning sites.

Methods

Data were collected during 15 trawl surveys on the Scotian Shelf (Figure 1) conducted from 1978 to 1985 (Table 1). All surveys employed large, fine-meshed midwater trawls specifically designed to capture pelagic juveniles. Headline transducers allowed exact determination of fishing depth. While the net design, fishing method, geographic coverage, timing, and target species varied, the principal objectives of all surveys were the collection of data on abundance, distribution, and behaviour of juvenile fish.

Surveys for herring were conducted in the Bay of Fundy on the R.V. E.E. Prince in February and August 1978 and February 1979. A Boris midwater trawl was used (headline length 23 m), fished during daylight hours at stations allocated randomly along a zig-zag search pattern and at locations where the ship's sounder indicated the presence of fish. The tow type was stepped oblique, with 10 min each near the bottom, midwater, and near surface, always beginning near the bottom.

Annual midwater trawl surveys for juvenile silver hake have been conducted in October and November since 1978 by various USSR research vessels as part of a Canada-USSR cooperative research program intended to provide year class size indices for the Scotian Shelf (NAFO Divisions 4VWX) stock. Stations were chosen randomly within three depth strata (Halliday and Koeller, 1981) over a broad area of the Shelf where adult silver hake were known to aggregate. During 1978 to 1980, the Soviet 13.6 Juvenile Trawl (headline length 24 m) was fishing for 30 min, near the bottom throughout, with fishing operations conducted on a 24-hr basis. The decision to fish near the bottom was based on the known on- or near-bottom vertical distribution of adults, in the absence of similar information for juvenile silver hake. Commencing in 1980, geographic coverage was restricted to areas where silver hake juveniles were abundant in previous years, and experiments were conducted to determine vertical distribution using methods described by Koeller (1981). Beginning in 1981, the International Young Gadoid Pelagic Trawl (IYGPT) was used (headline length 28 m), fished with a three-step tow as described for herring, except that operations were conducted only during hours of darkness. Three other silver hake surveys were conducted in November 1980, January 1981, and October 1981 on the R.V. Lady Hammond using the IYGPT to augment the geographic coverage and vertical distribution experiments conducted on the Soviet vessels.

Surveys for 0-group haddock were conducted in June 1983 aboard the R.V. Alfred Needler and in August 1983 aboard the R.V. Lady Hammond to collect information on distribution and abundance, as part of the Southwest Nova Scotia Fisheries Ecology Program. Fishing was conducted at stations along a systematic grid in the area off southwestern Nova Scotia, using the IYGPT fished in the three-step oblique fashion on a 24-hr basis. Tows were also made throughout the water column in June using the method described by Koeller (1981) to determine the vertical distribution of juvenile haddock. In addition, a special survey intended to determine the diel vertical distribution of juvenile cod was conducted in 1985 on the R.V. Alfred Needler.

Herring

The assessment of Atlantic herring populations in the Bay of Fundy is complicated by the absence of a fishery-independent index of recruitment to the juvenile fishery in a situation where the commercial fishery statistics are thought to be inadequate (Stephenson et al. MS 1985) and where a complex stock structure exists, consisting of many local components which use the Bay of Fundy as a nursery area.

Juvenile herring midwater trawl surveys were conducted in the Bay of Fundy to assess the feasibility of obtaining an abundance index for prerecruits (Koeller 1979). These surveys yielded new information on the distribution, movement, and origin of juveniles in the Bay of Fundy. For example, in February 1978, the new year-class (spawned in 1977) appeared mainly as larvae with a mode of 4 cm. This group was widespread and comprised most of the juvenile herring caught on the Nova Scotia side and at the mouth of the Bay of Fundy (Fig. 2). Presumably these larvae were spawned in the fall off southwest Nova Scotia and were carried into and across the Bay by prevailing currents as postulated by Iles and Sinclair (1982).

A second group of fish was also found, only slightly larger (modal length of 4.5 cm) than the larvae found throughout the Bay but completely metamorphosed, with all scales present. These fish were only found inshore in the Chignecto Bay area (Fig. 2) and probably originated from the Scott's Bay spawners, a population of fish known to spawn mainly in July and early August, slightly earlier than the main spawning population off southwestern Nova Scotia. In this instance, the progeny had remained relatively close to the assumed spawning location.

A third group of fish had a modal length of 7.5 cm and were widespread on both sides of the Bay of Fundy, but only above Saint John (Fig. 2). These fish were also concentrated inshore from Quaco Head into Chignecto Bay and were two years old (1976 year class) according to the convention for the area which assumes fall spawning and a birthdate of January 1. However, the modal length of 7 cm was much smaller than the average length of 2-yr-olds from commercial samples taken in the same month (13 cm). These smaller fish were probably spawned in the spring of 1977 and hence were actually just under one year old at the time of capture. This conclusion is consistent with previous records of spring spawners at the head of the Bay. While no obvious aggregations occurred, these fish had also remained fairly close to their inferred spawning grounds. In February 1979, the same groups of herring observed in the previous winter were again noted (Koeller, 1981).

In August 1978, catches consisted almost entirely of the new (1977) year class (Fig. 3). These fish were widespread along the New Brunswick side of the Bay of Fundy up to 16 km offshore. The smallest fish were found at the head of the Bay. These fish probably originated from the 1978 spring spawning and represented the new year-class of the comparatively small (mode 7.5, 1976 year class) fish captured during the February cruise. The latter group was still present at the head of the Bay in mid-August and was only slightly larger than the largest 1977 year-class fish also found there. These largest fish probably belong to the Scott's Bay spawning group previously seen in the area in February. Thus, some concentrations of local groups at the head of the Bay had maintained their position well into the second year of life. However, the most striking aspect of the length frequency distributions of the new year-class is that progressively smaller fish occurred from the mouth to the head of the Bay of Fundy. This suggests that some mixing had occurred along the coast between the spring spawned juveniles at the head of the Bay and larger fall-spawned fish at the mouth.

Our results indicate that surveys conducted during both the winter and summer present problems which could lead to significant errors in the estimation of juvenile herring abundance. During the winter (February), much of the new cohort is still at the larval stage and would not be completely retained by the juvenile trawls used, as well as being subject to significant mortality after the survey. In the summer, the new year class has begun to school, making the quantitative interpretation of data from midwater trawl surveys difficult. Although the application of acoustic methods could determine the required school density, size, and number in the survey area, the apparent mixing of stocks at the juvenile stage still presents a major problem in obtaining estimates for components of the stock complex. In any case, the prolonged spawning period from spring to fall in the Bay of Fundy would make a single survey of a year-class difficult because of differences in availability to the gear between sizes.

While midwater trawl surveys alone for juvenile herring are unlikely to produce accurate abundance estimates for assessments, their usefulness in stock discrimination studies is clearly demonstrated by the data presented above. Generally stock characteristics, as determined by electrophoretic, morphometric, or meristic methods, are derived from a sample of spawning fish. Since we were able to associate juvenile groups with spawning areas (Upper Bay of Fundy spring, Scott's Bay summer, and SW Nova Scotia fall spawners), it therefore appears possible to define discriminatory stock characteristics from samples of juvenile fish collected by midwater trawl, and compare them with the characteristics of their parents.

Silver Hake

The vertical distribution of silver hake was studied in October 1980 (0-group) and January 1981 (1-group) to determine if the methodology used during the first three surveys (1978-1980) was appropriate for obtaining abundance estimates with the precision required for stock assessments (Koeller, 1981) and in particular, whether the assumption of near-bottom distribution throughout the 24-hr day was correct. The observation that the highest mean catches during the synoptic surveys conducted in 1978 to 1980 were usually restricted to relatively short periods of the day near dawn and dusk (Fig. 4) suggested that this assumption required closer examination.

Vertical distribution experiments conducted in 1980 (Fig. 5) indicated that 0-group silver hake were found throughout the water column at night with relatively high concentrations above the thermocline. However, during daylight, silver hake were almost completely unavailable to the gear. A comparison of day vs night length frequencies from the 1980 synoptic surveys indicated that the daytime availability decreased abruptly at fish lengths between 20 and 30 mm (Fig. 6). However, there were no differences in day vs night availability between lengths above 30 mm that might be expected if net avoidance were involved, since large fish would presumably be more successful at avoidance because of their greater swimming ability. It was concluded that the change of availability of fish to the gear probably reflected the onset of diel migrations, including an on-bottom distribution by day. Such diel migrations would account for the observed dawn and dusk peak catches during the 1978-80 surveys when near-bottom sets were made, juveniles becoming available to the gear only at dawn and at dusk as they migrated past the near-bottom zone where the trawl was deployed. Sustained high catches during night sets made throughout the water column in 1981 support this view as did the increased catches of juveniles by day in a small-meshed bottom trawl (Fig. 7). Bowman and Bowman (1981) also found evidence for an on-bottom daytime distribution and a nocturnal upward migration in larger (> 20 cm) silver hake. Evidently, this behaviour begins when the fish are small (20 to 30 mm) and continues through much of their life. Bailey (1975) noted similar behaviour in juvenile Norway pout (*Trisopterus esmarki*) in the North Sea.

On the basis of the vertical distribution studies, the methodology of the synoptic surveys was changed from 24-hr fishing near bottom to a three-step, night only design. The change in the methodology was associated with an increase in the precision of the abundance estimates (Table 2). For example, in 1981, the first year that the new method was used, precision was greatest even though both the stratified and unstratified mean catches were also the highest noted during the series.

For silver hake it is apparent that the near bottom trawl deployment method during 24 hours contributed substantially to the variance of the abundance estimate. Other problems with the method can be inferred. Since vertical migration is probably related to ambient light levels, it is likely that weather conditions will influence catches during daylight hours. This could bias results if the average number of cloudy days, for example, varies substantially during the survey period from year to year. Slight differences in gear deployment could also bias results, such as when the trawl on occasion is brought nearer to the bottom than usual during the day, or farther off bottom then usual at night.

It should be noted that the new methodology employed after 1980 is not without problems, since it assumes uniform distribution throughout the water column at night. This is unlikely to be the case, particularly during periods of active migration, and would lead to serious biases if the fish at any time concentrate vertically between the three layers (near-bottom, midwater, and near surface) sampled. However, it is improbable that a more directed tow could be implemented which would cover all the variations in vertical distribution likely to be encountered during a survey for juvenile silver hake. The ultimate usefulness of any survey series to assessments can only be determined by comparing the results with independant estimates of abundance after many years of surveys. Considering the investment of resources that such a survey series represents, the above results show that an initial investment in vertical distribution studies is warranted.

The incorporation of information on geographical distribution is no less important than that on vertical migrations in the design of a juvenile survey. In cases where previous information is lacking, as wide a coverage as possible with available resources seems prudent, although information from preliminary surveys may subsequently allow better definition of the survey area. The distribution of 0-group silver hake juveniles on the Scotian Shelf as determined from the midwater trawl surveys in October-November of each year from 1978 to 1983 is given in Fig. 8. As a result of the wide coverage of the Shelf achieved in 1978, 1979, and 1981, we concluded that 0-group silver hake were widely distributed but were found mainly in the deeper strata (>120 m) west of 62° longitude. This contrasts with the distribution of eggs and larvae which show more discrete concentrations mainly east of 62° longitude, in water shallower than 80 m (O'Boyle et al., 1984). Since both eggs and larvae appear to concentrate in the same areas (O'Boyle et al., 1984), the westward shift of silver hake and the dispersion over a wider area appears to occur mainly in the late larval and early juvenile stages. These results indicated that even for widely distributed species such as silver hake, the distribution of juvenile fish may differ markedly from both larvae and adults, and that survey area must be based on distribution determined from preliminary juvenile surveys. However, the apparent drift of late larvae and early juveniles also indicates that too small a survey area could bias results in years where substantial drift carries a large part of the population outside the survey area.

The length composition of silver hake catches revealed another potential difficulty with surveys for the species. Two modes were apparent in the length-frequency distributions of silver hake caught in the central Scotian Shelf (Fig. 9). The increased separation of the modes during October 1980 to January 1981 may reflect differential growth rates or an increased rate of recruitment of late-spawned juveniles to the fishing gear. The wide range in lengths illustrates the importance of survey timing for silver hake. The species has a prolonged spawning time of July to October (O'Boyle et al., 1984) requiring that survey time be delayed until all late spawned 0-group fish are available to the gear. This was apparent during the 1978-1980 surveys when relatively large numbers of newly metamorphosed fish and some yolk sac larvae were caught. After 1980, the surveys commenced later in the year and the problem did not recur. However, the possibility of differences in availability to the gear for species with prolonged spawning times, particularly for fish at either end of the length frequency, should be kept in mind when evaluating juvenile survey results. The problem was also noted for whiting (Merlangius merlangus) by Heessen et al. (1982).

A possible origin of the smaller mode in Figure 9 is apparent from examination of Fig. 10, where length frequencies are given by area. If the smaller juveniles from the northeast were displaced to the southwest by the Nova Scotia current (Sutcliffe et al., 1976) and mixed with larger juveniles originating from an earlier spawning, a feasible hypothesis for the bimodal length-frequency distributions found on the central and southwestern portions of the Scotian Shelf could be offered. Again, this illustrates the utility of juvenile surveys in stock discrimination studies, as well as in studies of larval drift and identification of spawning areas. We further demonstrate the potential of juvenile midwater trawl surveys in marine fisheries biology by way of an example. In addition to the two major modes described above, we also noted the occurrence of a periodic polymodality in the length-frequency distributions of silver hake, a feature which was particularly evident in 1981 when the length range was wide and large numbers of fish were measured. The periodicity was most evident when the data were smoothed with a 3 mm moving average (Fig. 11). The periodicity did not appear to result from sampling biases as the modes of measurements made onboard two independent and coincident cruises were similar and were not associated with group marks on the measuring boards (eg. 10 or 5 mm marks). The modes were approximately 5 mm apart, which represents about two weeks growth at rates in the same order as those apparent from the modal shift of the larger group in Fig. 9 (about 30 mm in 2 mo) between November and January. Therefore, it is possible that the observed periodicity in lengths was due to a fortnightly, tidally induced spawning periodicity such as was described for other marine fish species (Battle, 1930; Taylor, 1984). Silver hake are known to be sequential spawners, with each female producing at least three batches of eggs a year (Sauskan and Serabryakov, 1968). This example illustrates that, properly timed, juvenile surveys can be conducted after many of the significant early life history events have occurred, but before evidence of their occurrence has been masked by subsequent events. In the above example it is unlikely that a single larval survey could have produced the same information due to the comparatively narrow size range of animals collected by plankton gear, and the probable occurrence of spawning both prior to and after such a survey. Similarly, measurements of adult fish would not have yielded evidence of fortnightly spawning, since differential growth among individuals would have masked it.

Haddock

Due to a lack of previous information from the area, the first annual juvenile haddock survey in NAFO Div. 4X (June 1983) used the three step (near bottom, midwater, near surface) tow type for the synoptic coverage stations, working 24 hrs per day. A vertical distribution experiment was conducted during the survey in an area of haddock abundance, to determine the best method of trawl deployment during subsequent surveys. Results from this experiment indicated that juvenile haddock are found near the surface both during day and night (Fig. 2). Examination of catches from the synoptic survey also showed no significant differences in catches with time (Mann-Whitney test, $p < 0.05$). Based on these results, it was apparent that the three-step, 24 hour methodology provided an unbiased estimate for haddock, but also that during 2/3 of the duration of each tow the trawl was below the depths where haddock concentrated. Consequently, trawling was restricted to the upper 50 m of the water column in surveys conducted for haddock after 1983. Our results do not preclude diel vertical migration within the shallow zone prior to descent to the bottom. Scott (1984), for example, found evidence of diel migrations in 0-group haddock in the shallows surrounding Sable Island. Nor do they preclude diel migrations off the bottom following the ontogenetic descent. Both phenomena would complicate survey design.

The June 1983 survey revealed other aspects of 0-group haddock biology which may be pertinent to the development of year-class size indices for this species. Figure 12 shows the association of haddock with the large jellyfish Cyanea sp. near the surface. Diver observation confirmed the association, as did the coincident geographic distribution of the two species in June 1983 (Fig. 13). At this time the association of juvenile fish with Cyanea appeared to be specific to haddock, as indicated by a multiple regression analysis with Cyanea as the dependent variable and the main species caught during the survey as the independent variables (Table 3). In August, this association was no longer apparent (Fig. 13). Haddock had descended to the bottom and Cyanea had moved inshore by this time.

Although the exact nature of fish-jellyfish associations remains obscure (Mansueti, 1963), such associations may have interesting ramifications for design of abundance surveys. The presence or absence of Cyanea may influence the duration of the pelagic phase, thus affecting the optimum time for conduct of a pelagic survey. Conceivably a survey design for juvenile haddock, stratified on the basis of Cyanea distribution determined from surface observations, could reduce the variance associated with abundance indices and the effort required in obtaining adequate geographic coverage.

The residence time of juvenile haddock in the water column is an important consideration in midwater trawl survey design. On the basis of two midwater trawl surveys conducted during June and early August and three bottom-trawl surveys conducted in May, July, and September of 1983, we were able to determine that descent to the bottom occurred from mid June to early August, when the fish were about 7-8 cm in length (Fig. 14). This relatively abrupt ontogenetic migration presents a serious obstacle to the reliable estimation of abundance over a large area. If separate spawning populations exist within the area surveyed, different spawning times or developmental rates may result in different descent times. Interannual variations in environmental or biological factors may also affect the time of descent. Such variations may account for the relative scarcity of juvenile haddock on Georges and Brown's Bank (Fig. 13) in 1983, areas where late-juvenile and adult populations of haddock are known to occur, and where concentrations of eggs and larvae were found earlier in the year (P. Hurley, unpublished data). Haddock had probably already descended to the bottom on Georges and Browns Bank at the time of the June survey and were unavailable to the survey gear. The concentration of juveniles found on the eastern edge of the survey area may have originated from spawning groups on the La Have, Roseway, or Baccaro Banks, or even from spawning to the east of the survey grid, having drifted into the survey area in association with Cyanea. A single pelagic abundance survey for juvenile haddock may not be possible even in an area as small as NAFO Divs. 4X and 5Ze without serious bias caused by different descent times of juvenile groups.

Atlantic Cod

A preliminary indication that diel migrations might influence juvenile cod abundance indices was obtained during the haddock survey conducted in August, 1983, when it was found that the median lengths of cod caught at night were significantly greater than those caught during the day (Mann-Whitney test, $p < 0.01$, Fig. 15), similar to what was observed for silver hake above. This suggested that larger fish move up in the water column at night, increasing the median size of fish in the sample and accounting for the greater range of sizes observed. However, an alternative hypothesis of net avoidance by larger fish during the day could also account for the observed results. During the study of diel migrations conducted in 1985, we found that the proportion of juvenile cod caught in the more shallow portions of the water column increased at night (Fig. 16) supporting the migration hypothesis. However, total numbers caught were also significantly greater at night (Mann-Whitney test, $p < 0.01$) as were the mean lengths of fish captured at all three depths sampled (two-way analysis of variance $p < 0.01$, Fig. 17), which could also be interpreted as supporting the avoidance hypothesis. We favour the migration hypothesis on the basis of ancillary observations including, for example, that large haddock (>60 mm) were captured during the day at the surface, suggesting that if similar sized cod were present at the time they would also have been captured. The inference of diel migration, however, contrasts with the observations of Bailey (1975) and Robb (1981) who found little evidence of diel vertical migations in

0-group North Sea cod.

The cod data illustrates a major problem with the use of midwater trawls for abundance surveys and behavioural studies. It is often difficult to determine whether changes in catch rates are due to vertical migration or to gear avoidance, yet the action taken to improve the methodology of an abundance survey may depend on which phenomenon actually occurs. While there is little doubt that a night-only survey design (as eventually adopted for silver hake) would result in greater precision of abundance estimates for cod, regardless of whether the differences in diel catch rates were due to migration or net avoidance, a viable 24 hr. design might still be implemented in in the case of net avoidance with appropriate gear changes (eg. net or mesh sizes, towing speed, net colour, type, etc.). Similarly, if vertical migration is the problem, appropriate fishing depth changes with time of day, or use of a semipelagic trawl capable of on bottom fishing by day may also allow full use of the 24 hr fishing capability of most research trawlers. Where doubt exists as to which behaviour is actually occuring more direct observations are warranted, for example, with net mounted cameras, submersibles, or acoustic equipment.

Conclusions

Results from the juvenile surveys conducted on the Scotian Shelf indicate that multispecies midwater trawl surveys to obtain abundance estimates for pelagic juveniles are probably not feasible in the Northwest Atlantic. Major differences in juvenile distribution and behaviour between species requires a species-specific survey methodology. Diel migration patterns, in particular, differ substantially among the species observed, requiring a tow type and timing during the day designed for the target species. Moreover, diel migrations or changes in availability may vary on an intraspecific basis, as demonstrated by the diel, length specific changes in cod catchability. The exact nature of these changes is often obscure but their cause must be determined before the optimum methodology for an abundance survey can be designed. Residence time in the water column will differ between species with different spawning and/or developmental rates, requiring that survey timing during the year be species-specific to ensure availability of as much of the new year-class as possible. However, ontogenetic migrations may also vary on an intraspecific basis. For example, in NAFO Divs. 4X and 5Ze haddock, descent times to the bottom may vary between groups of fish, requiring several synoptic surveys of the area to sample the entire population. Finally, geographic distribution of juvenile fish is also unique to the species and the life history stage, further substantiating our belief that a survey for more than one species requires a compromise in design that results in substantially higher variance of abundance estimates for some or all species surveyed.

Midwater trawl surveys of juvenile fish populations are a means of collecting critical data on distribution and life history. Such fundamental studies must be conducted prior to their use in the estimation of abundance. A final concern which remains unaddressed is whether the abundance estimates obtained from midwater trawl surveys, no matter how accurate, are indicative of subsequent recruitment to the fishery. The importance of events subsequent to the time of an 0-group survey must therefore be examined. Recent work in the North Sea, for example, (Daan, 1984) indicates significant predation on the juveniles of commercially important species.

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Table 1. Midwater trawl surveys conducted from 1978 to 1983.

Target Species	Vessel	Cruise No.	Dates	Area	Midwater Trawl Used	Standard Tow Type
Herring	E.E. Prince	P192	15/2-2/3/78	Bay of Fundy	Boris	3-step day only
	"	P203	21-31/8/78	"	"	"
	"	P214	3-11/2/79	"	"	"
S. Hake	Viandra	VY03	27/9-17/10/78	Scotian Shelf	Soviet 13.6 Juvenile Trawl	Near bottom 24 h
	Vykhma	VN04	4-27/10/79	"	"	"
	60-Let	LE03	28/9-31/10/80	"	"	"
	Lady Hammond	H044	29/10-10/11/80	"	IYGPT	"
	"	H046	6-15/1/81	"	"	"
	Eklyptika	EK03	19/10-6/11/81	"	"	3-step night only
	"	EK05	31/10-14/11/82	"	"	"
	Lady Hammond	H066	27/10-9/11/81	Southwestern Scotian Shelf	"	"
Haddock	Alfred Needler	N011	20-30/6/83	"	"	3-step 24 h
	Lady Hammond	H0104	1-12/8/83	"	"	
Cod	Alfred Needler	N047	17-29/6/85	"	"	*3-step 24 h top 50 m

* all other surveys using the 3-step method sampled near bottom, midwater, and near surface.

Table 2. Juvenile silver hake abundance indices and associated measures of precision, Scotian Shelf 1978 to 1983.

	n	Unstratified X	Unstratified s.d.	Unstratified c.v.	Stratified X	Stratified s.e.	Stratified s.e. (%) / $\bar{X}$
1978[a]	55	166.11	443.64	267	235.57	98.37	42
1979[a]	55	180.67	849.03	470	56.42	20.98	37
1980[a]	100	26.83	57.55	214	26.03	5.36	21
1981[b]	77	610.71	614.27	101	578.34	70.63	12
1982[b]	61	7.26	9.96	137	8.74	1.96	16
1983[b]	64	223.63	238.72	107	225.60	23.37	10

[a] Near bottom tows, conducted during both day and night, with Soviet Juvenile Trawl

[b] Near bottom, midwater, near surface tows, conducted at night only using the IYGPT

Table 3. Multiple regression analysis of Cyanea vs cod, butterfish, and haddock using data from a pelagic trawl survey conducted in June 1983, vicinity of Browns and Georges Bank.

Independent Variable	Coefficient (b)	St. Dev. of Coefficient	t ratio b/s.d.
Cod	-0.00496	0.01149	-0.43 ns
Butterfish	0.3521	0.3373	1.04 ns
Haddock	0.37999	0.09498	4.0 **

** $p < .01$

df = 65

$R^2 = 0.179$

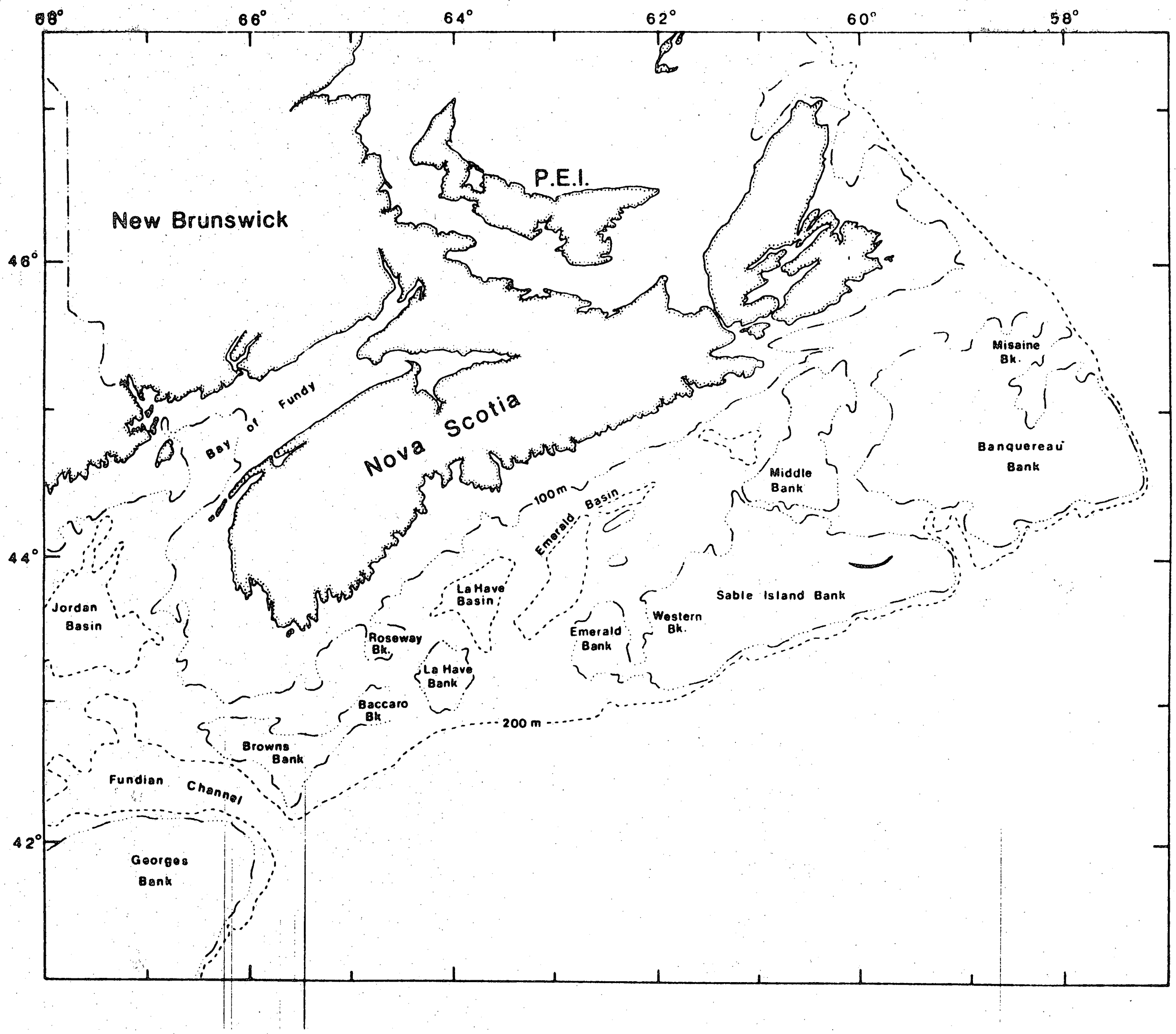

Figure 1. The Scotian Shelf, showing geographic features referred to in this paper.

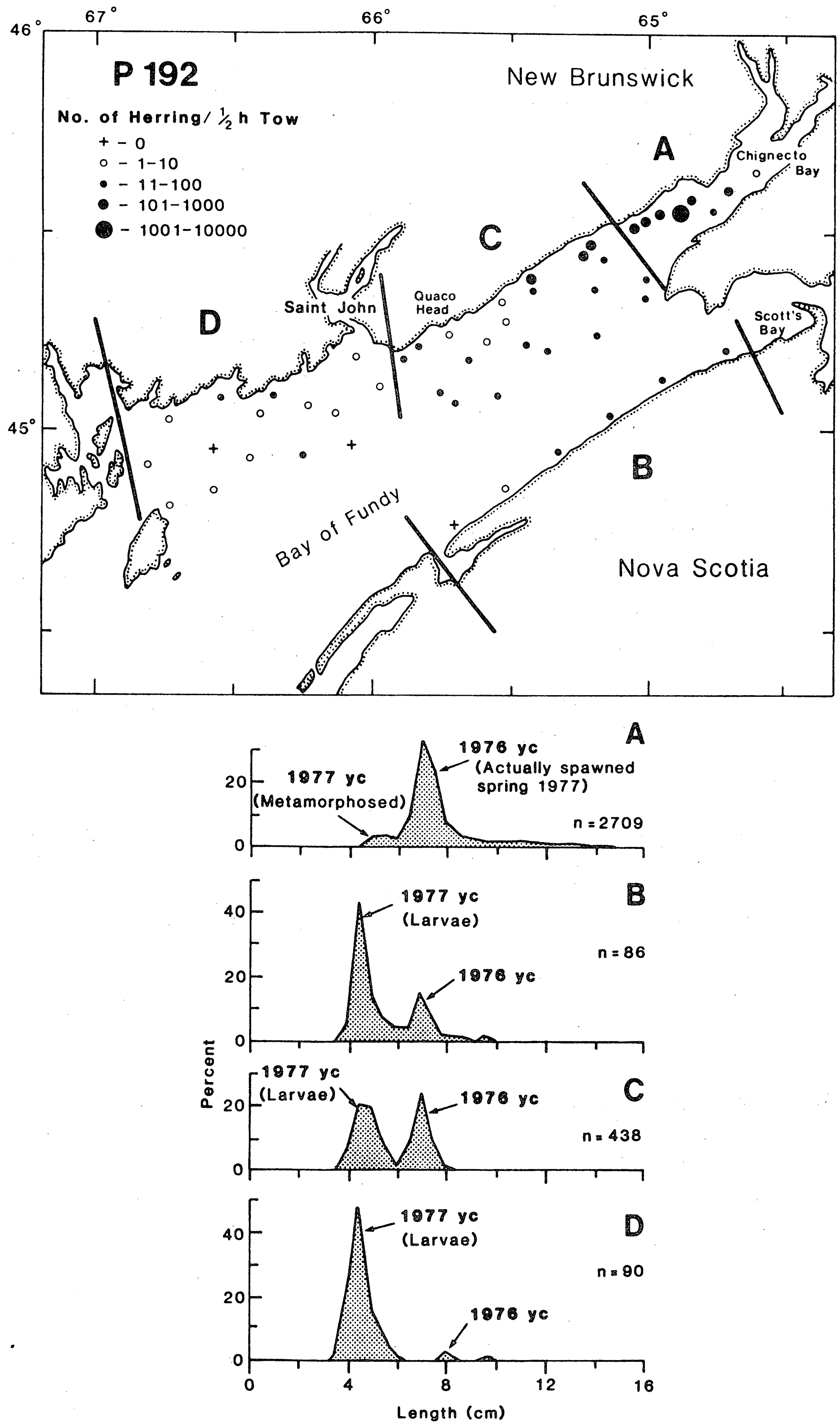

Figure 2. Catches of juvenile herring in a survey of the Bay of Fundy, February 1978. The length-frequency distribution of the catches at the various locations throughout the Bay (indicated as A to D) are shown in the histograms (adapted from Koeller, 1980).

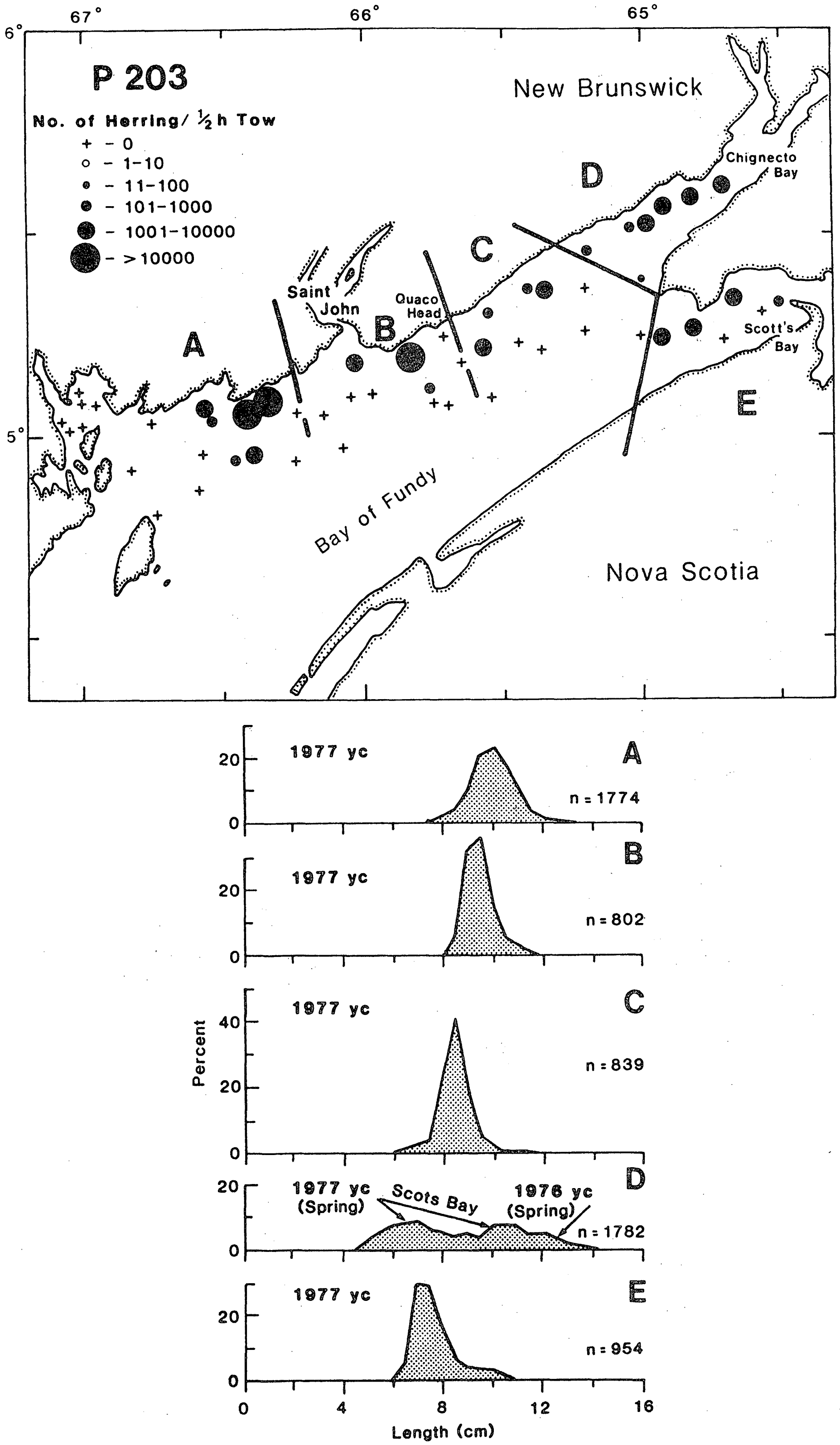

Figure 3. Catches of juvenile herring in a survey of the Bay of Fundy, August 1978. The length-frequency distribution of the catches at the various locations throughout the Bay (indicated as A to E) are shown in the histograms (adapted from Koeller, 1980).

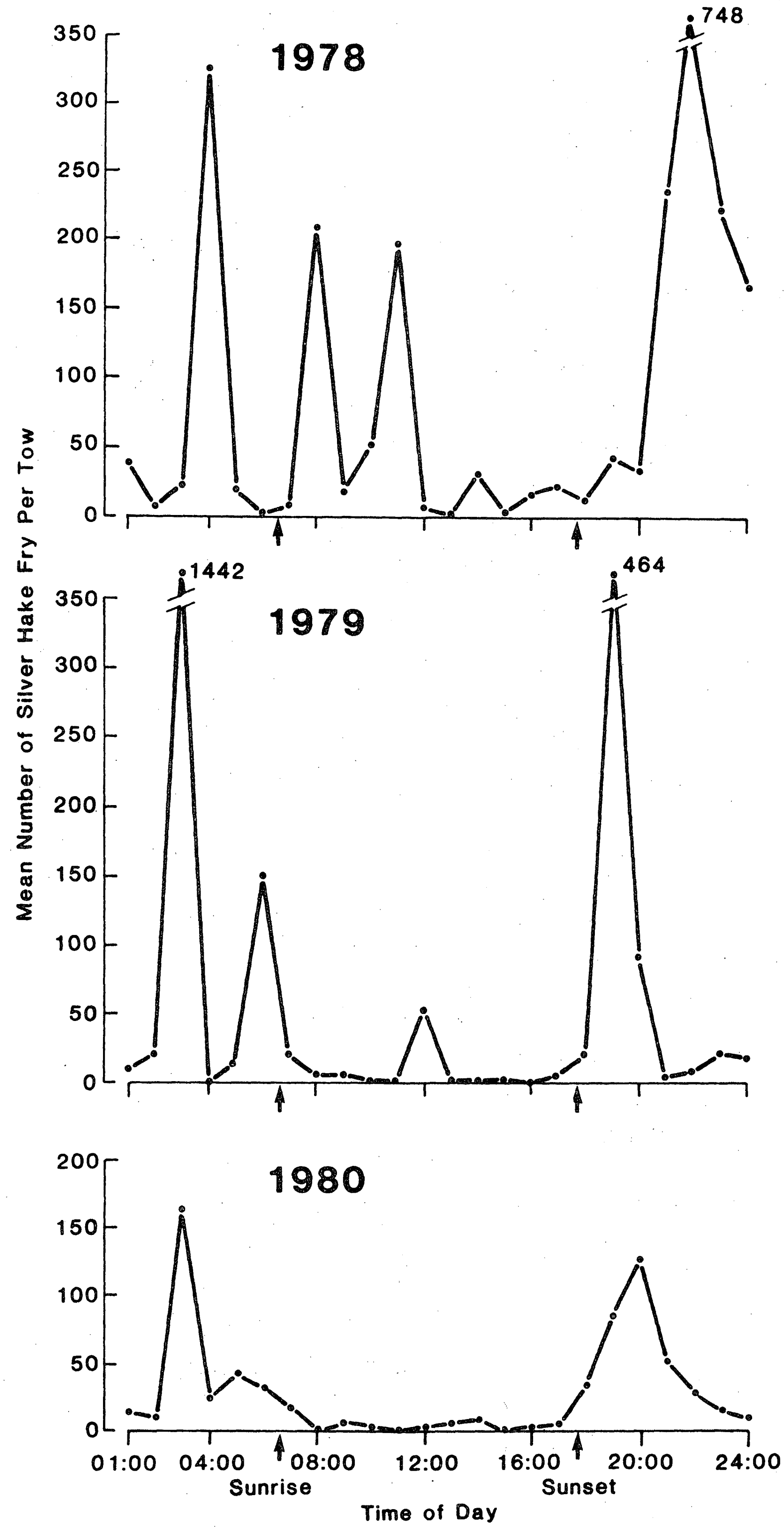

Figure 4. Changes in catch rate with time of day during the Canada-USSR silver hake 0-group surveys on the Scotian Shelf, 1978 to 1980 (from Koeller, 1981).

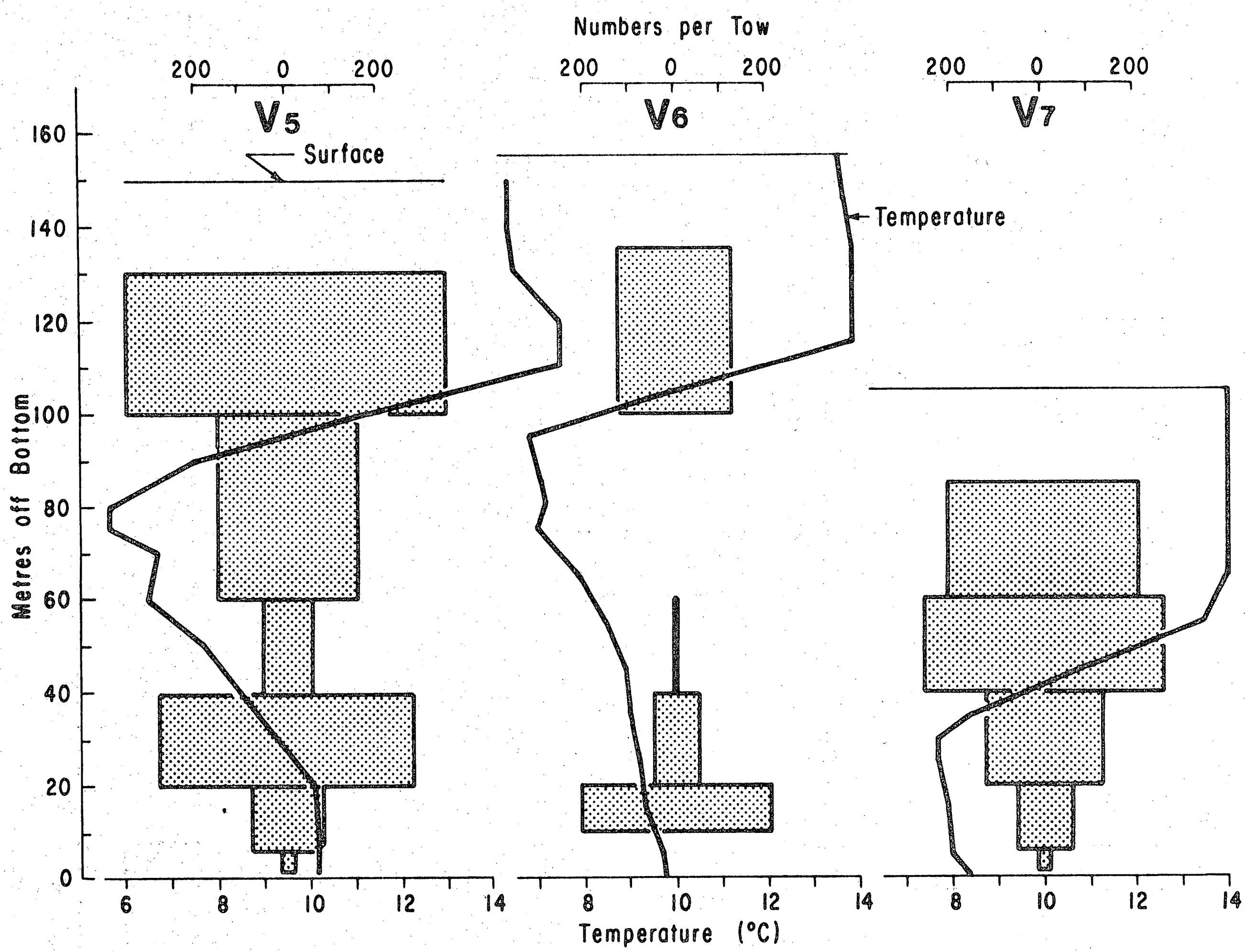

Figure 5. The distribution of catches of 0-group silver hake at three locations on the Scotian Shelf (V5, V6, and V7) at night (1800 to 0700 h), 1980. The data were corrected to account for fish caught as the net was ascending and descending to the particular depth strata sampled. Catches during day profiles were negligible, or nil. Temperature profiles were obtained by Expendable Bathythermograph.

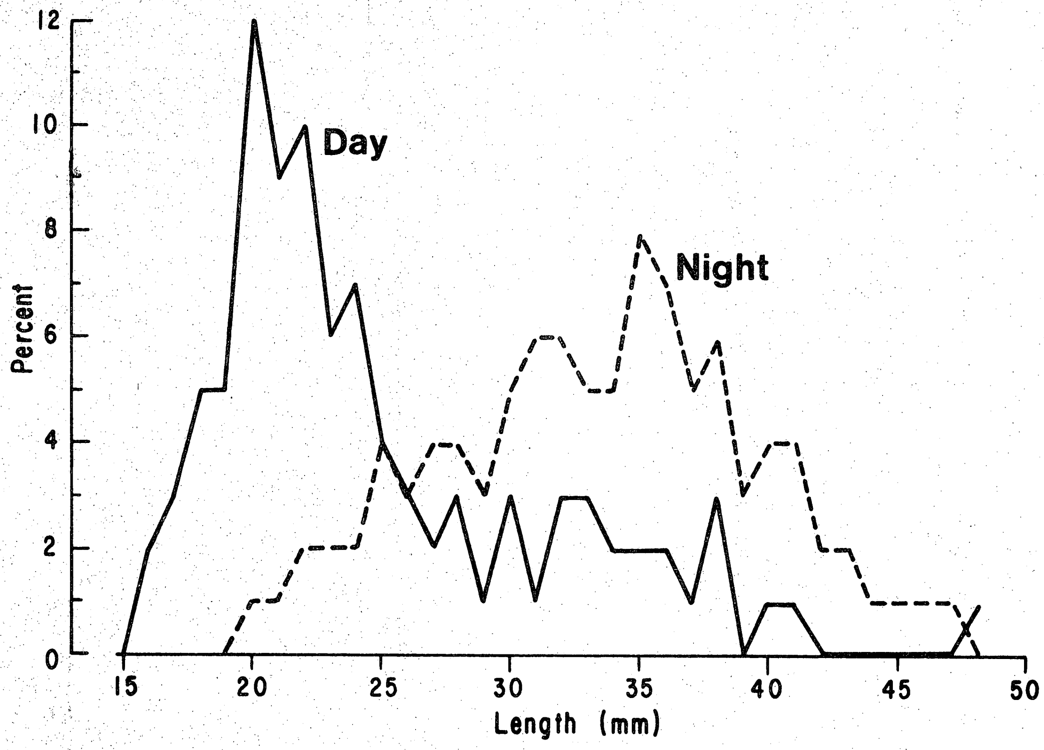

Figure 6. Length-frequency distribution of 0-group silver hake caught during day (0700 to 1800 h) and night (1800 to 0700) in the regular survey sets of the 1980 joint Canada-USSR study on the Scotian Shelf.

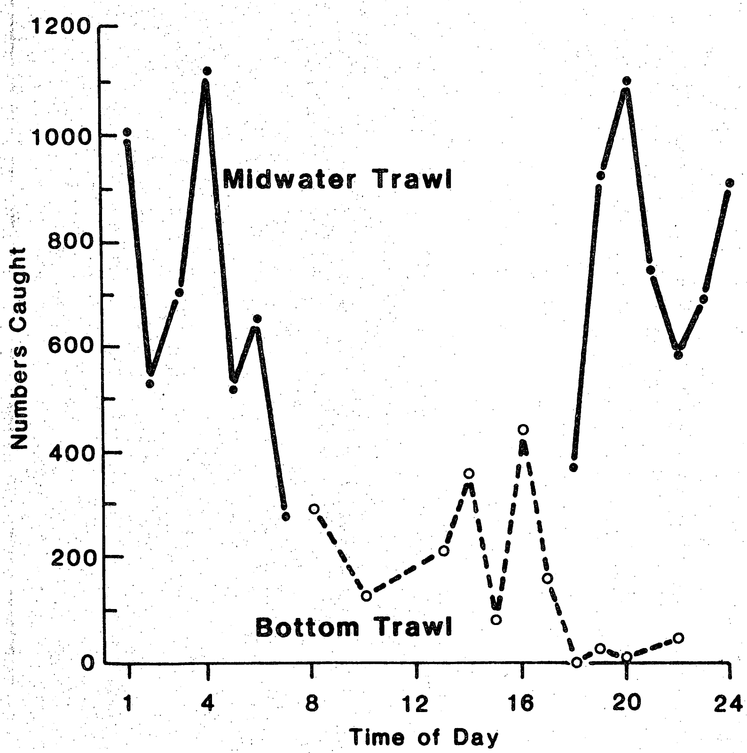

Figure 7. Numbers of 0-group silver hake caught in both midwater and bottom trawls during joint Canada-USSR research conducted on the Scotian Shelf in 1980.

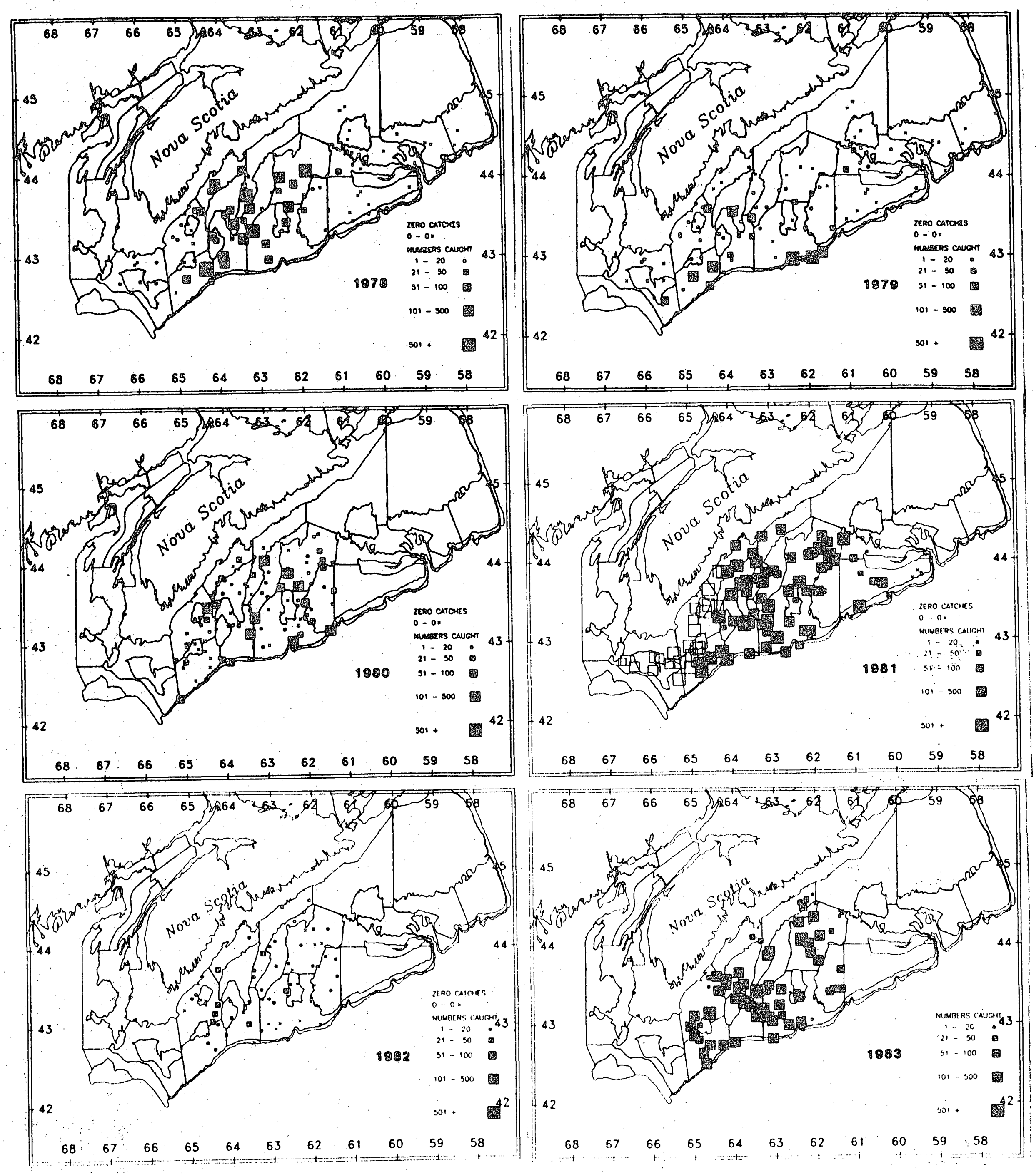

Figure 8. Distribution of catches of juvenile (0-group) silver hake in joint Canada-USSR midwater surveys on the Scotian Shelf, 1978 to 1983. The open squares in the 1981 plot denote sets made by a Canadian research vessel (Lady Hammond), supplementing those of the joint survey further to the east. The boundary lines represent strata boundaries.

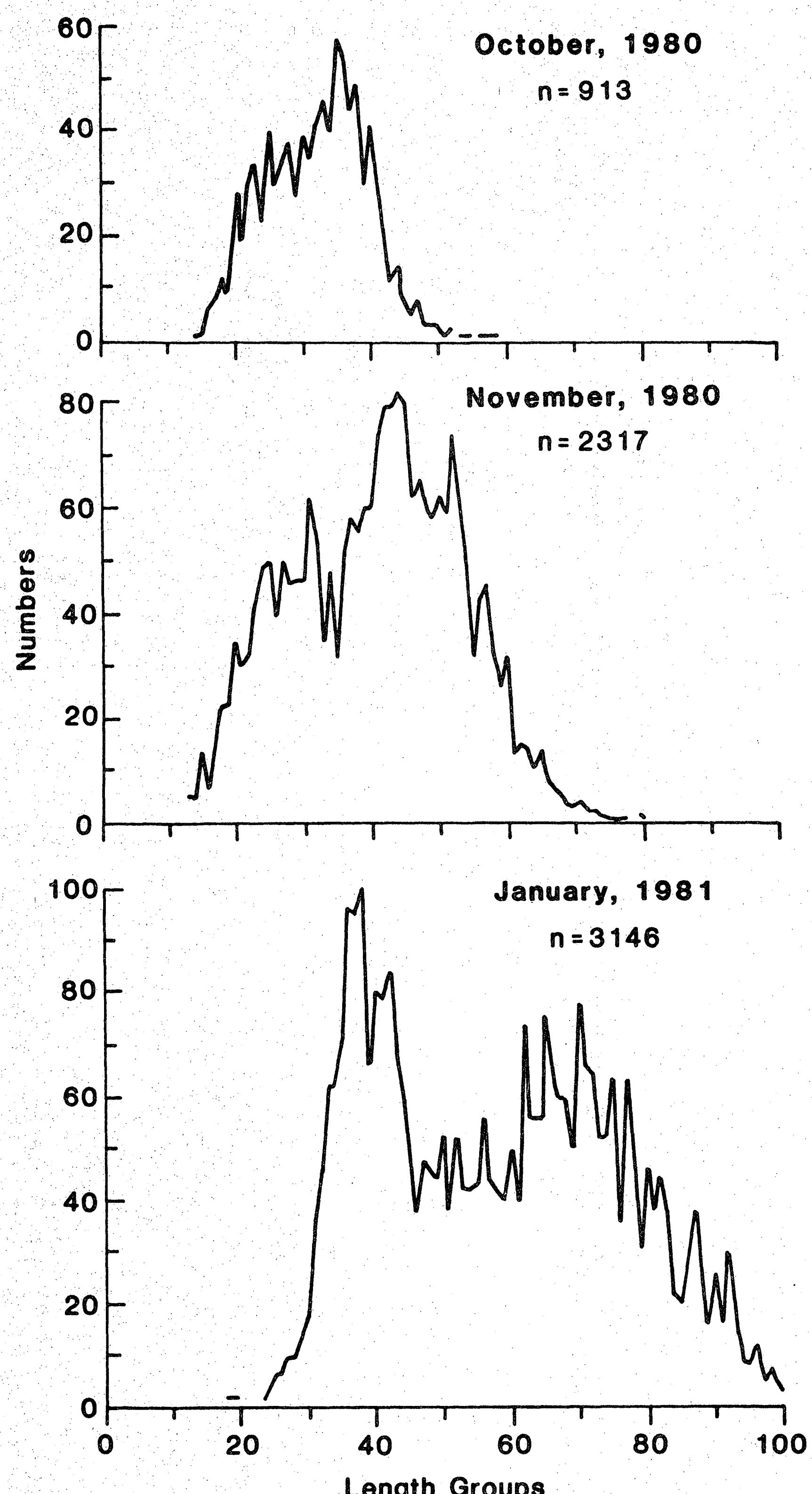

Figure 9. Length-frequency distribution of 0-group silver hake collected in joint Canada-USSR midwater surveys of the Scotian Shelf from October 1980 to January 1981.

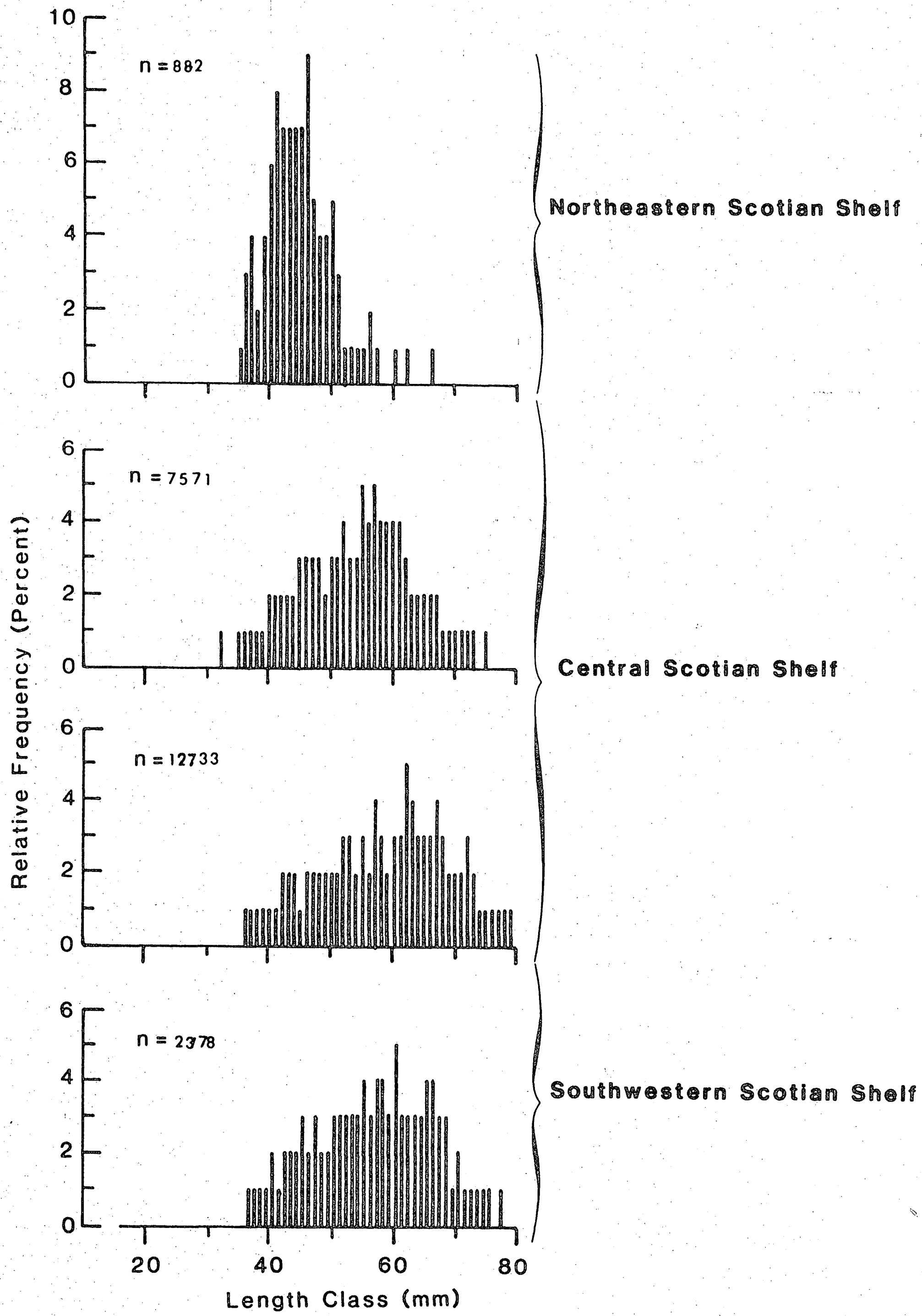

Figure 10. Length-frequencies of 0-group silver hake from 3 areas of the Scotian Shelf obtained during the 1981 joint Canada-USSR midwater trawl survey.

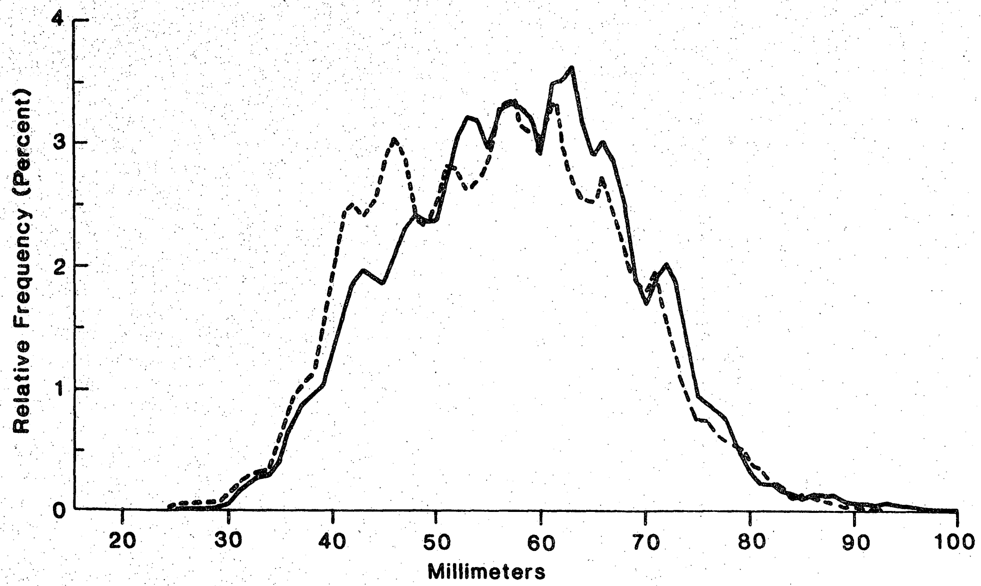

Figure 11. Length-frequency distributions of 0-group silver hake caught during Canada-USSR surveys on the Scotian Shelf conducted in 1981. Data are smoothed by 3 mm moving averages. Dashed line - measurements made on Soviet vessel. Solid line - measurements made on Canadian vessel.

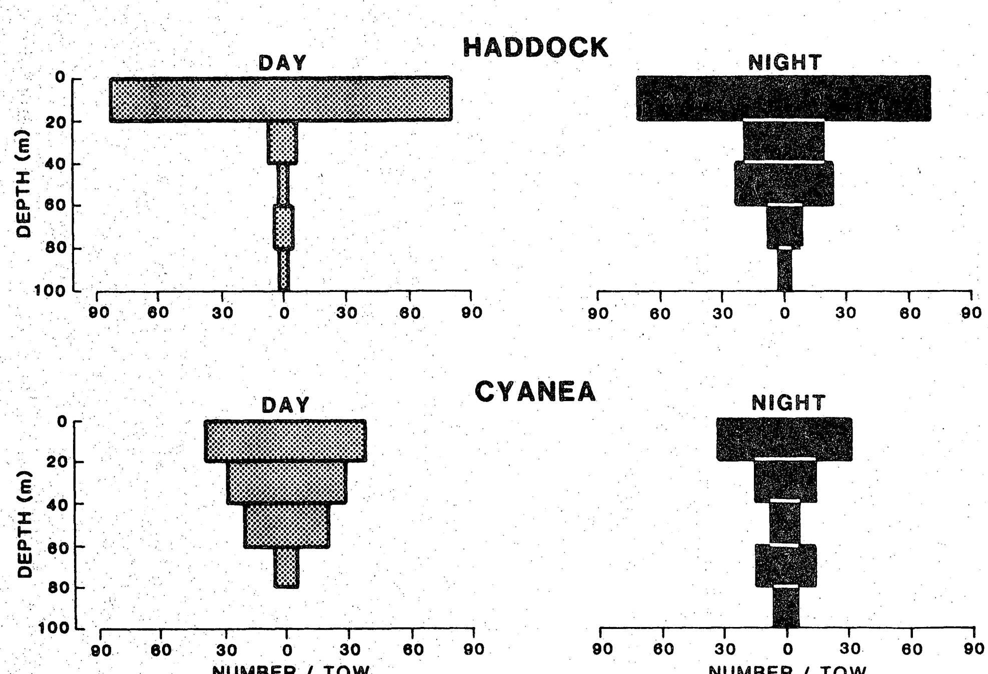

Figure 12. The depth distribution of 0-group haddock and Cyanea sp. in day and night sets made during a vertical distribution experiment conducted off south-western Nova Scotia, June 1983. The distributions were determined through depth-stratified sampling with an International Young Gadoid Pelagic Trawl.

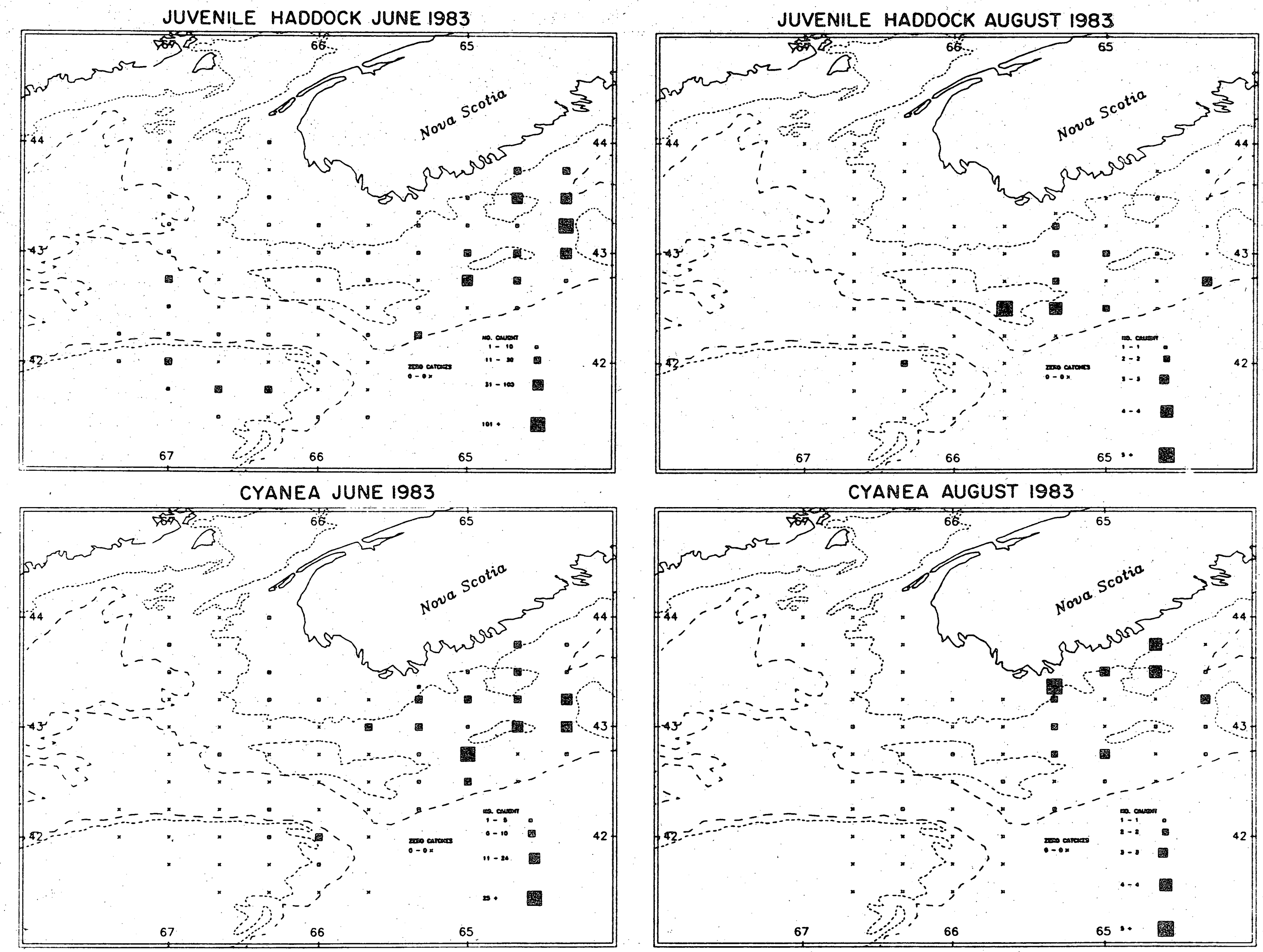

Figure 13. The geographic distribution of 0-group haddock and <u>Cyanea</u> sp. in a pelagic trawl survey conducted off south-western Nova Scotia, June 1983.

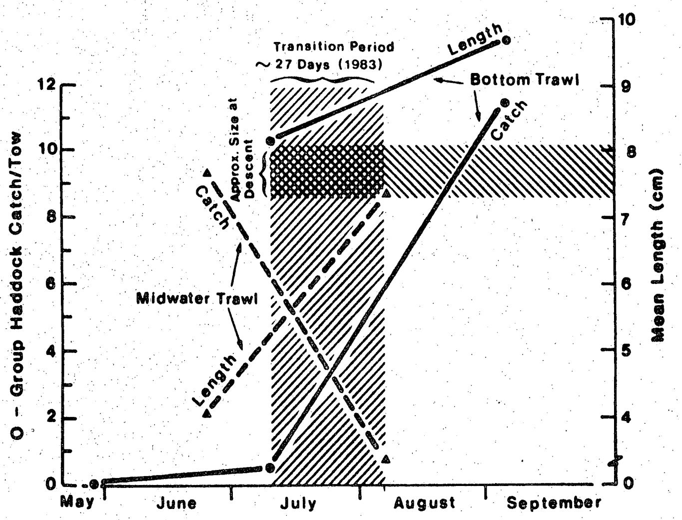

Figure 14. The time and size of 0-group haddock at the transition to the demersal habitat, as inferred from a series of midwater and bottom trawl surveys conducted in 1983 off southwestern Nova Scotia.

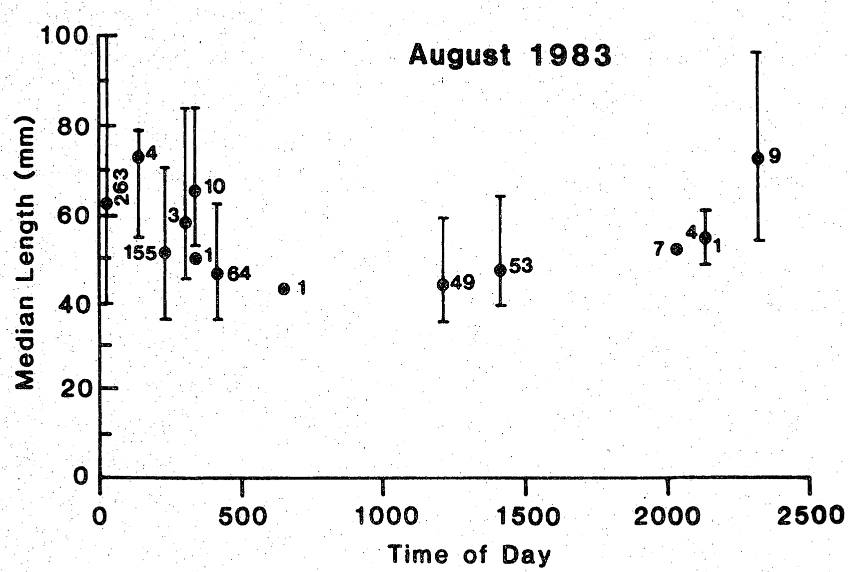

Figure 15. The median lengths of 0-group Atlantic cod caught during pelagic trawl surveys versus time of day. South-western Nova Scotia, August 1983.

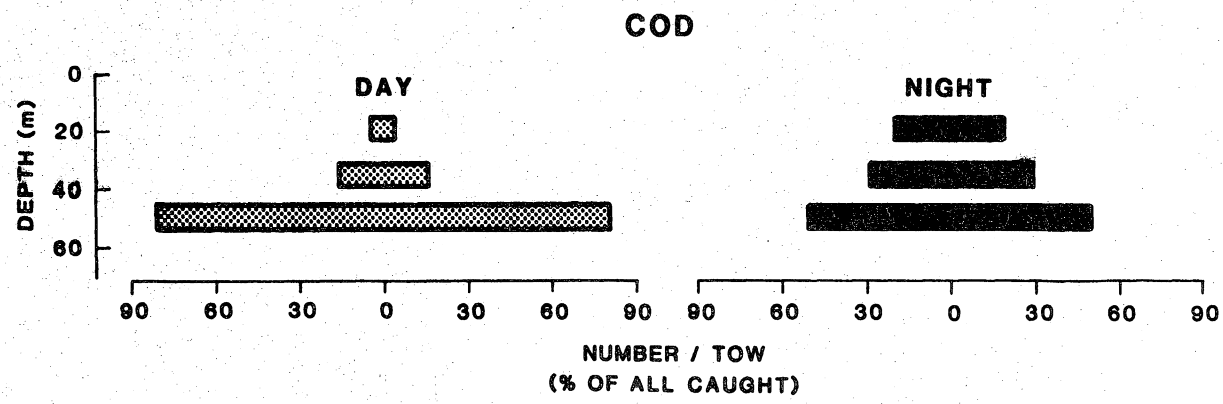

Fig. 16. The vertical distribution of O-group Atlantic cod in day and night sets made during a vertical distribution experiment conducted off south-western Nova Scotia, June 1985. The distributions were determined through depth-stratified sampling with an International Young Gadoid Pelagic Trawl. Six sets were made at each depth, both day and night.

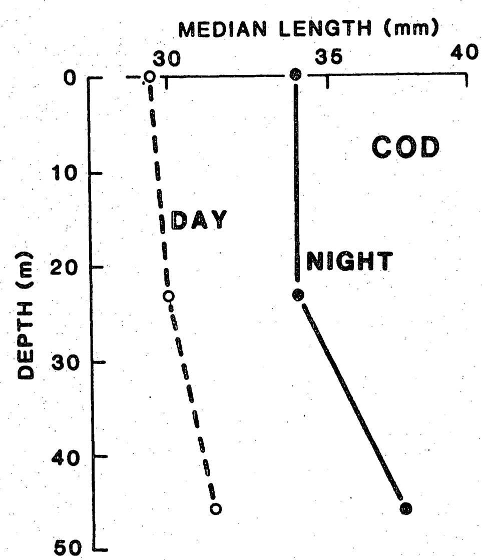

Figure 17. The median lengths of O-group Atlantic cod in day and night sets made during a vertical distribution experiment conducted off south-western Nova Scotia, June 1985. The distributions were determined through depth-stratified sampling with an Internatonal Young Gadoid Pelagic Trawl. Six sets were made at each depth, both day and night.