NAFO Sci. Coun. Studies, 11: 53-61

Some Characteristics of Atlantic Herring (*Clupea harengus*) Spawning in the Southern Gulf of St. Lawrence

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Abstract

Spawning locations of Atlantic herring (*Clupea harengus*) in the southern Gulf of St. Lawrence were identified by aerial photographic surveys of gillnet distributions in 1980-83. Although the spawning locations remained basically the same as in the past, except for minor variations, the relative abundance of the spawning groups in the spring and autumn (late summer) fisheries has changed over the years from a traditional spring fishery to a situation where the spring and autumn fisheries are both substantial. Nevertheless, the regularity of the timing of spawning remained the same. Spring-spawning herring arrive on the spawning grounds in late April or early May, and autumn-spawners arrive in August and stay until the end of September. Analysis of data on the spawning time of spring-spawners showed a significant inverse relationship betwen the timing of herring arrival on the spawning ground and mean water temperature. Cold years resulted in late spawning and warm years resulted in early spawning. Analysis of vertical sections of water temperature distributions indicated a rapid reduction in volume of cold water ($\leqslant 0°$ C) from April to May. It is hypothesized that the size and depth of the cold layer influence the onset of spawning migration. Overwintering herring continue to stay in the deep warm layer until the time when the overlying cold layer has shrunk to such an extent that herring can move to the shallow spawning grounds without having to swim through the cold layer which cover the shallow areas earlier in the spring.

Introduction

Perley (1850), in his reports on sea and river fisheries of New Brunswick, noted that "the common herrings appear in the Gulf of St. Lawrence at the end of April, or early May, and the fishery continues until about 10th June, when they retire to deep water, having deposited their spawn ... . Another herring appears on the coast about the 20th August and remains inshore for a month...". The situation today is similar to that of 135 year ago, in that two spawning populations of herring occur in the Gulf of St. Lawrence: spring spawners and autumn spawners. Each group comprises a complex of components which spawn at various localities in the southern Gulf (Messieh, 1975). Previous studies have shown significant correlations between the arrival of herring on the spawning grounds and surface temperature (Messieh, MS 1977).

The present study was undertaken to identify the spawning locations and spawning times and to examine the factors which regulate the time of arrival of herring on the spawning grounds. The spawning locations were determined from distributions of herring gillnets during aerial photographic surveys. The time and duration of spawning were determined from observations of the arrival of herring on the spawning grounds and the analysis of maturation stages of maturing and spawning fish. The role of temperature in determining the timing of herring migration from overwintering areas to the spawning grounds in the spring is explored.

Materials and Methods

Aerial photographic surveys were carried out during the spring herring fishery in the southern Gulf of St. Lawrence in 1980, 1981 and 1983, with the aim of determining the distribution and intensity of gillnets which had been deployed on and near the spawning grounds. A standard gillnet is 27.4 m long and 3.7 m deep, and strings of these nets were easily identified on composite photographs, which had a ground scale of 1/6,000 $\pm$ 5%. The surveys covered all spring herring fisheries in the southern Gulf (Fig. 1), and each area was photographed 4-7 times per fishing season. In addition to gillnet distributions, the presence of algae on the substrate near the shore and information from interviews with fishery officers and experienced fishermen in the various regions were used to identify the herring spawning locations.

Scuba-diving surveys of herring spawning beds were carried out in the springs of 1981, 1983 and 1984 and in the autumn of 1985. The spring surveys were conducted on a major spawning ground at Escuminac in Miramichi Bay, New Brunswick, and the autumn survey was carried out on Fishermans Bank off southeastern Prince Edward Island. These locations were chosen because they are the centers of major herring fisheries in the southern Gulf of St. Lawrence. These surveys provided information on substrate characteristics and allowed estimation of the sizes of spawning beds and intensities of egg deposition (Pottle *et al.*, 1980; Messieh *et al.*, 1985).

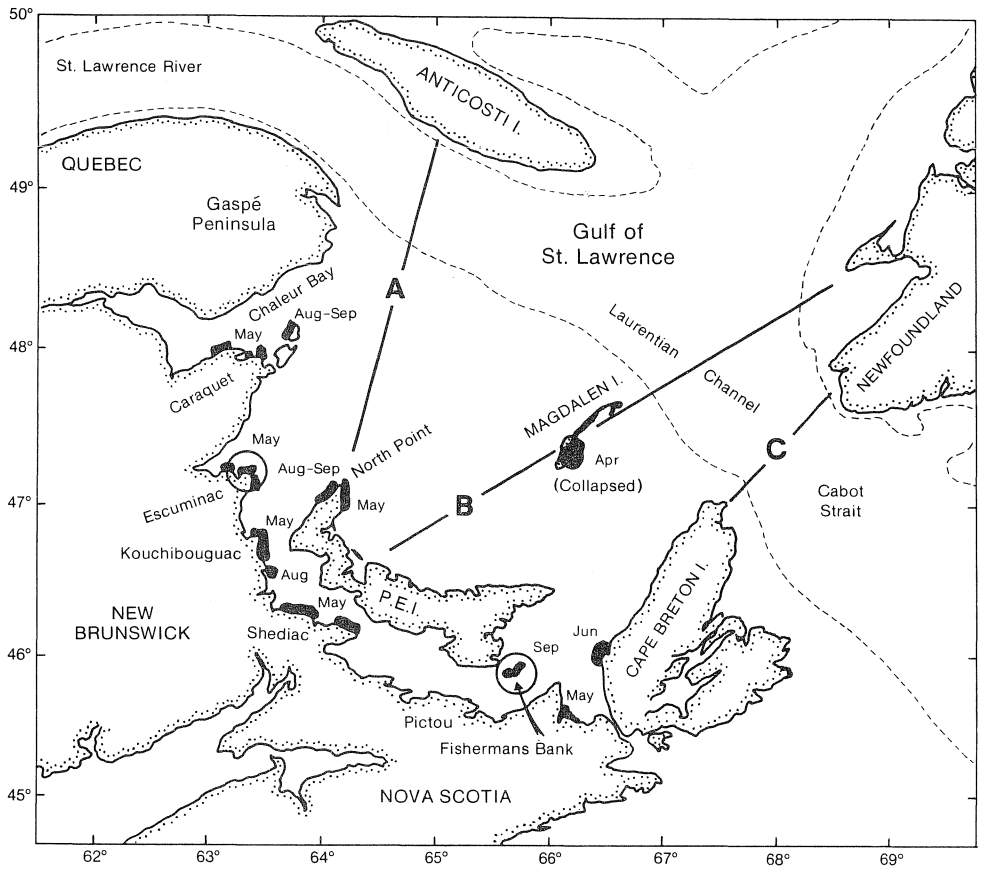

Fig. 1. Spring and autumn spawning grounds of herring in the southern Gulf of St. Lawrence, and three hydrographic sections for which temperature data were summarized. (Circled spawning locations were investigated by scuba-divers.)

The durations of the spawning periods for spring-spawning and autumn-spawning herring populations were determined from analysis of maturity stages in many samples, comprising more than 30,000 herring, which were collected during the prespawning and spawning periods in 1966-84. Analysis of the samples by week and fishing area enabled the identification of spawning peaks with a good degree of precision. Spawning was considered to have reached its peak when more than 50% of the herring in the samples were in the ripe and running condition.

To elucidate the role of temperature in the timing of herring arrival on the spawning grounds, vertical profiles of temperature along three sections across the Laurentian Channel were examined (Fig. 1). All available temperature data from research vessel surveys of the area during April and May of 1965-79 were compiled and analyzed, with the assistance of the Marine Environmental Data Service (MEDS), Ottawa, Canada.

Results and Discussion

Inferred spawning locations from aerial surveys

From the aerial surveys of gillnet distributions in May of 1980, 1981 and 1983, the major spring herring fisheries in the southern Gulf of St. Lawrence were located in the general vicinity of Caraquet, Escuminac, Kouchibouguac and Shediac in New Brunswick and at North Point in Prince Edward Island (Fig. 2-6), all of which have been important historically. In general, the spawning grounds have remained approximately the same for many years except for small variations in some areas. In the Caraquet area (Fig. 2), the fishery has shifted a few kilometers westward from the vicinity of Caraquet to Belloni Point. In the Shediac area (Fig. 5), gillnet distributions were variable, with a concentration on the historical spawning ground near Fagan Point in 1980 and a westward shift of the main concentrations in 1981 and 1983. The Escuminac spawning grounds in 1980-83 (Fig. 3) were in approximately the same locations as historically and the herring concentrations there supported the largest inshore herring fishery in the Gulf of St. Lawrence. There was little variation in the gillnet distributions over the 1980-83 period in the Kouchibouguac (Fig. 4) and North Point (Fig. 6) areas.

Spawning bed characteristics

The substrate of the Escuminac spawning grounds can be described generally as rocky with sandy patches, covered with seaweeds. Irish moss

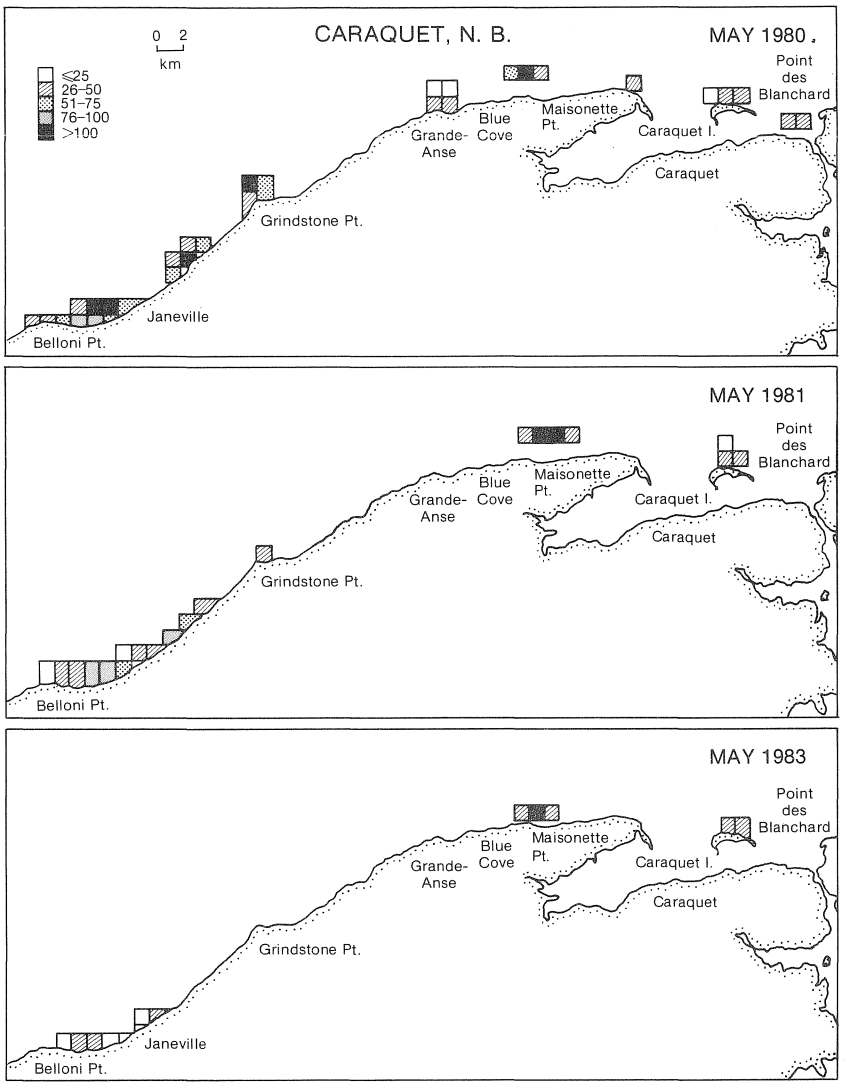

Fig. 2. Spring-spawning locations in the Caraquet area, as inferred from aerial photographic surveys of herring gillnet distributions in May, 1980–83. (Intensity is shown as number of standard nets per square kilometer.)

(*Chondrus crispus*) was the dominant macrophyte in the area, followed by rockweeds (*Fucus* sp.) and leafweeds (*Phyllophora* sp.). The physical characteristics of the substrate at Escuminac were similar to those of the spawning beds in Chaleur Bay (about 100 km north of Escuminac), which were described by Tibbo *et al.* (1963). At Escuminac, herring eggs were distributed over a depth range of 0.8–5.0 m, with the largest concentrations in 1.5–4.0 m. The lack of eggs deeper than 5 m was probably due to the sandy bottom and lack of vegetation. The attachment of a high proportion of the eggs to Irish moss was probably due to the widespread distribution of that seaweed rather than to a preference for it by herring. In all 3 years of observation, spawning occurred during the first 3 weeks of May, and egg deposition varied from scattered eggs to patches which were 1–5 layers thick. The major predator was winter flounder (*Pseudopleuronectes americanus*). The incubation period varied from 14 to 19 days, depending on water temperature which ranged from 3.3° to 9.7° C during the spring surveys.

The substrate of the autumn-spawning bed on Fishermans Bank consisted mainly of bedrock and rubble, with negligible algal cover. Spawning occurred in waves during 5–26 September 1985. Herring eggs were distributed evenly like a thick carpet over a depth range of 15–20 m and were deposited in several layers with maximum thickness of 4.5 cm. Major predators were Atlantic mackerel (*Scomber scombrus*) and winter flounder. The incubation period lasted about 10 days, with water temperature as high as 17° C.

The size of the spring-spawning beds and the intensity of egg deposition at Escuminac varied greatly (Table 1). In 1981, the spawning area was only 42,500

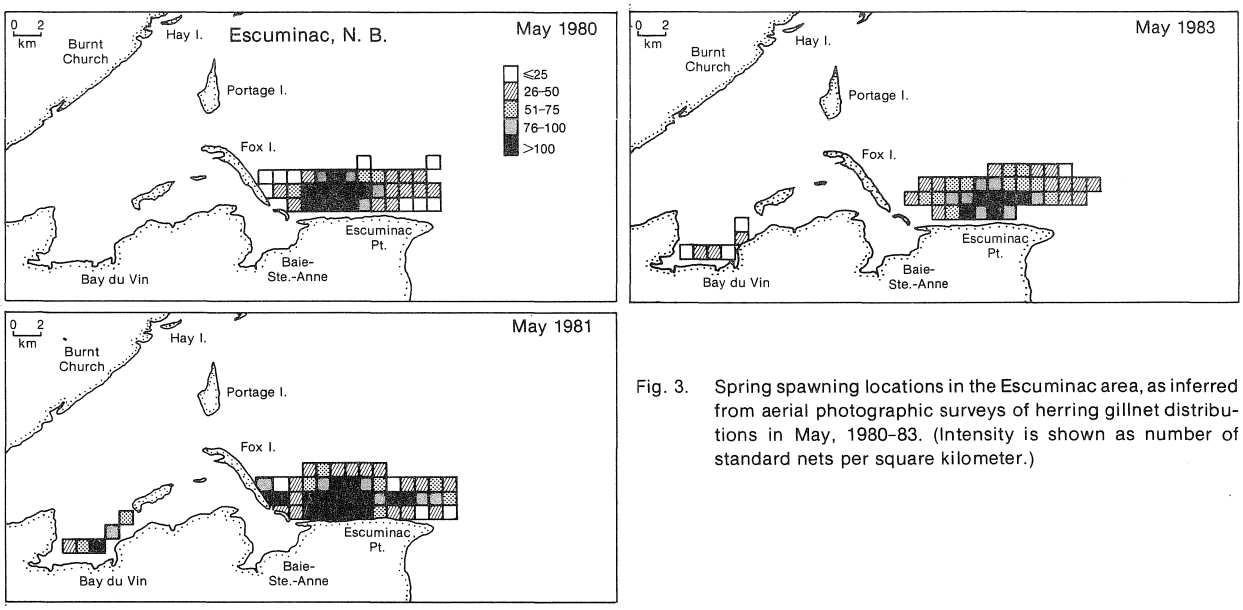

Fig. 3. Spring spawning locations in the Escuminac area, as inferred from aerial photographic surveys of herring gillnet distributions in May, 1980–83. (Intensity is shown as number of standard nets per square kilometer.)

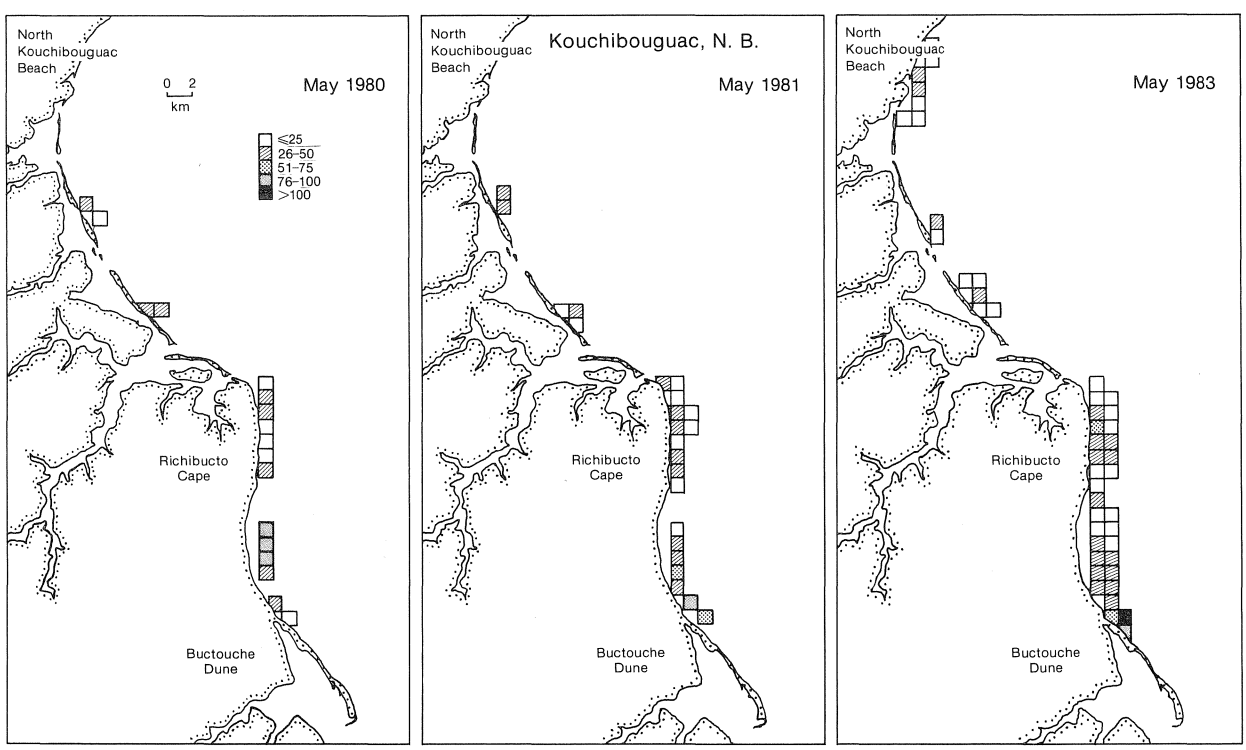

Fig. 4. Spring-spawning locations in the Kouchibouguac area, as inferred from aerial photographic surveys of herring gillnet distributions in May, 1980–83. (Intensity is shown as number of standard nets per square kilometer.)

m^2 and egg intensity was very low at 1,760 eggs/m^2. In 1983, the single spawning bed was 20 times larger than in 1981 and egg intensity was also much higher at 24,700 eggs/m^2. In 1984, spawning was distributed over three beds with a total area exceeding 2,000,000 m^2, and mean egg intensity (80,000/m^2) was more than 3 times higher than in 1983. Egg intensity was extremely variable among the four autumn-spawning beds on Fishermans Bank in 1985 (Table 1), but, nevertheless, egg deposition was very high with the average intensity being 3,560,000 eggs/m^2, much higher than had been observed on the spring-spawning grounds.

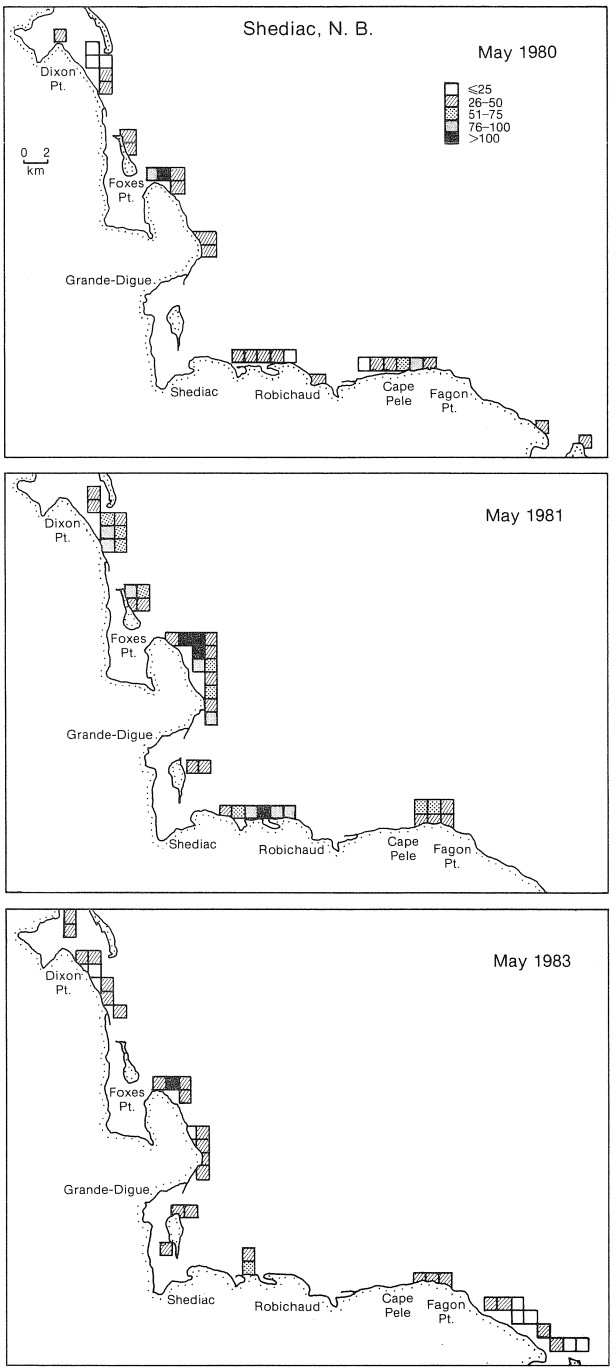

Fig. 5. Spring-spawning locations in the Shediac area, as inferred from aerial photographic surveys of herring gillnet distributions in May, 1980–83. (Intensity is shown as number of standard nets per square kilometer.)

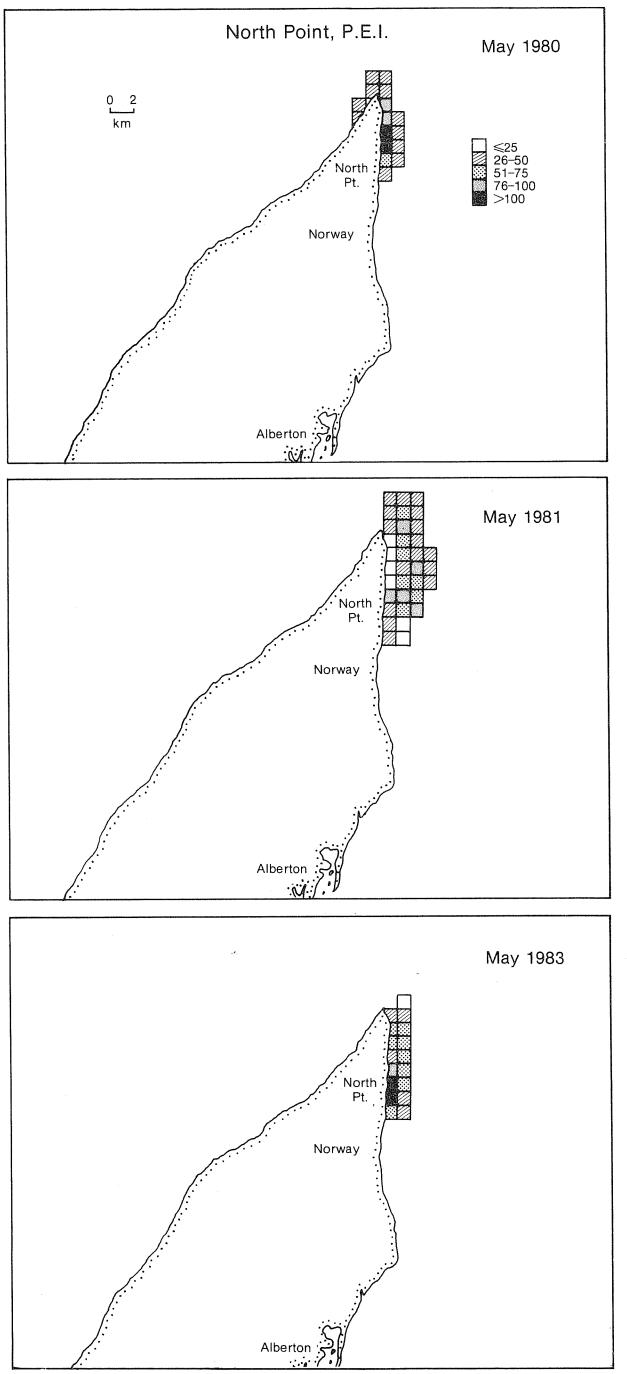

Fig. 6. Spring-spawning locations in the North Point area, as inferred from aerial photographic surveys of herring gillnet distributions in May 1980–83. (Intensity is shown as number of standard nets per square kilometer.)

Time of herring arrival on spawning grounds

The inshore fishery in the southern Gulf of St. Lawrence is based mainly on the exploitation of spring-spawning and autumn-spawning populations during their occurrence on or near the spawning grounds close to shore. This fishery is conducted with gillnets and extends from late April to late September with peaks during the spawning seasons. Feeding concentrations of these populations are exploited during the summer in the offshore region from the Gaspé Peninsula to the Magdalen Islands. In late autumn, both spawning types move eastward to the edge of the

Laurentian Channel and thence to overwintering areas in the fjords of southwestern Newfoundland and eastern Cape Breton Island as well as in deep water along the Laurentian Channel (Hodder, 1969, 1971; Winters and Hodder, 1975).

The relative importance of the spring-spawning and autumn-spawning components in the fishery has changed over the years. Nevertheless, the regularity of spawning times is clearly demonstrated by the seasonal distributions of gillnet catches during the 1949–84 period (Fig. 7). Until the mid-1960's, the herring catches were comprised mostly of spring-spawning fish with peaks in May. The autumn fishery expanded during the late 1960's and early 1970's and catches were sometimes larger than those of the spring fishery. Spring-spawning herring arrive on the spawning grounds in late April or early May and spawning is over by the end of May or early June. Autumn-spawners arrive on the spawning grounds in late July or early August and stay until the end of September.

TABLE 1. Size of herring spawning beds and intensity of egg deposition in major spring and autumn spawning locatons surveyed by scuba-diving in the southern Gulf of St. Lawrence, 1981–85.

Season	Year	Location of spawning beds	Spawning area (10^3 m^2)	Egg intensity (N × 10^3/m^2)
Spring	1981	Escuminac (1)	30.0	2.0
		Escuminac (2)	12.5	1.2
	1983	Escuminac	880.0	24.7
	1984	Escuminac (1)	560.0	85.9
		Escuminac (2)	445.0	34.2
		Escuminac (3)	1,100.0	95.8
Autumn	1985	Fishermans Bank (1)	286.0	2,590.0
		Fishermans Bank (2)	489.0	250.0
		Fishermans Bank (3)	239.0	4.7
		Fishermans Bank (4)	807.0	6,960.0

Spawning duration inferred from maturity stages

Analysis of herring samples from the spring and autumn fisheries of 1966–84 in five major spawning areas of the southern Gulf of St. Lawrence enabled estimation of the spawning periods for the spring and autumn spawners and the weeks in which peak spawning occurred (Fig. 8).

The fishery around the Magdalen Islands was based solely on spring-spawning herring. In the 1960's, spawning occurred from mid-April to late May with peaks from the last week of April to the second week of May. In the 1970's, none of the samples provided evidence of peak spawning. The lack of major spawning coincided with the collapse of the fishery and the dominance of non-spawning fish in the limited catches of

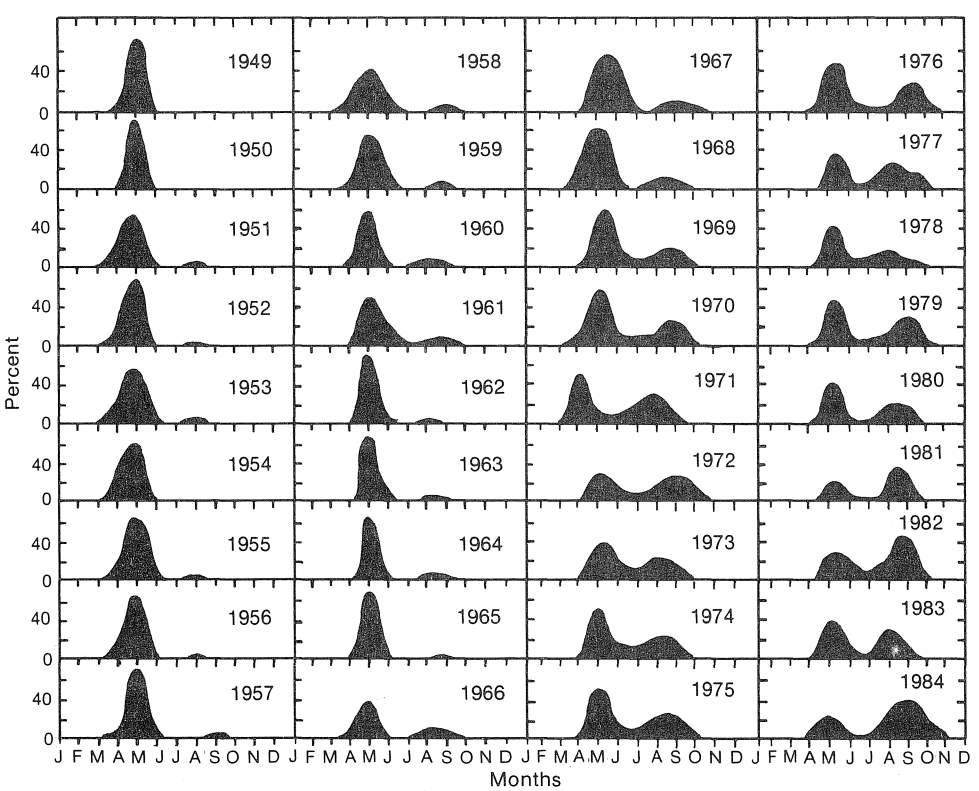

Fig. 7. Relative abundance of spring-spawning and autumn-spawning herring, as inferred from the seasonal pattern of gillnet catches in the southern Gulf of St. Lawrence (Div. 4T), 1949–84.

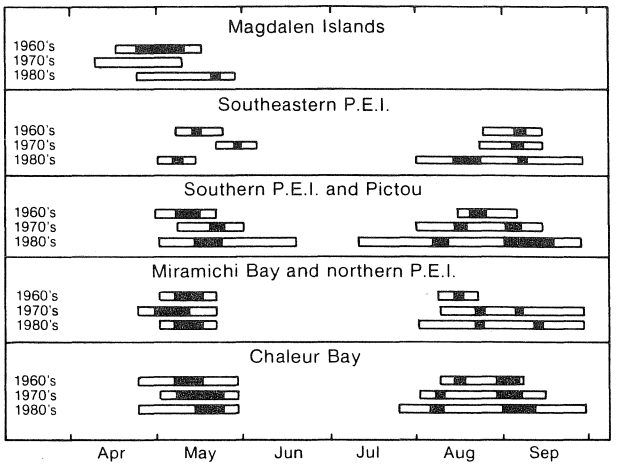

Fig. 8. Time and duration of spring and autumn spawning of herring in five areas of the southern Gulf of St. Lawrence by decades for 1966-84, as inferred from analysis of maturity stages in herring samples collected during the prespawning, spawning and postspawning periods. (Black bars indicate peak spawning when more than 50% of the fish were mature.)

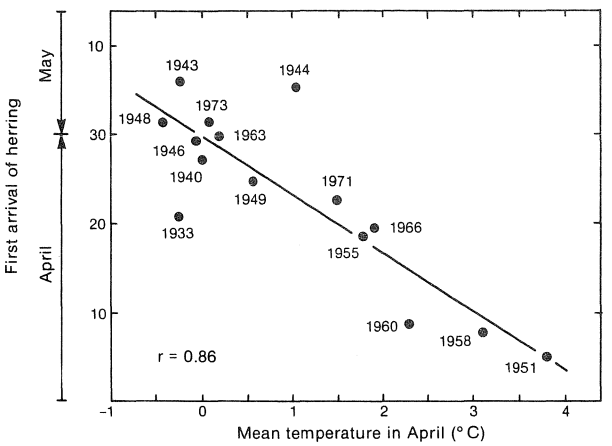

Fig. 9. Relationship between the time of first arrival of spring spawners and surface temperature on the spawning grounds at Magdalen Islands, from sporadic observations during 1933–73. (From Messieh, MS 1977.)

that period. Recovery of the population occurred in the 1980's with the appearance of mature herring on the spawning grounds in 1984 when peak spawning occurred in late May.

In southeastern Prince Edward Island, the spring-spawning period generally extended over a period of 3 weeks with considerable variation in the time of peak spawning, which ranged from the second week of May in the 1980's to the first week of June in the 1970's (Fig. 8). Autumn (or late summer) spawning in this area extended over a much longer period in the 1980's (9 weeks) than in the 1970's (4 weeks), with major spawning in mid-August and early September, in contrast to early September only during the 1960's and 1970's.

In the south Prince Edward Island-Pictou area (Fig. 8) spring spawning usually occurred during May in the 1960's and 1970's, but there was an extension of the spawning period to late June in the early 1980's, although the peak period in May was approximately the same as in the earlier decades. The autumn-spawning period in this area was rather short (4 weeks) in the 1960's, became longer in the 1970's (7 weeks) and was still longer (11 weeks) from mid-July to late September in the 1980's, with peaks in early August and in early to mid-September in the 1970's and 1980's.

In Miramichi Bay, there was very little variation in the timing and duration of spring spawning on the Escuminac grounds (Fig. 8). In some years, the spawning period was limited to only 2 weeks. Autumn spawning occurred off northwestern Prince Edward Island and extended from 3 weeks (peak in mid-August) in the 1960's to 8-9 weeks in August and September of the 1970's and 1980's, with peaks in late August and early to mid-September.

In the Chaleur Bay area (Fig. 8), spring spawning extended from late April to early June in all three periods with considerable regularity. Autumn spawning in this area exhibited increased duration of the season from about 4 weeks in the 1960's to 10 weeks in the 1980's, with biomodal spawning peaks in early August and early September.

Effect of temperature on time of spring spawning

Examination of the relationship between the arrival time of herring on the spawning grounds near Magdalen Islands and mean surface temperature showed a linear relationship between these two variables (Fig. 9). That study was based on occasional observations of the actual time of arrival of herring on the spawning grounds during 1933–73 (Messieh, MS 1977). Spawning occurred in late April and early May of cold years and in early April of warm years. The effect of water temperature on fish yield, production and recruitment has been discussed by many researchers (e.g. Jakobsson, 1969; Templeman, 1972; Cushing, 1982), and various authors have offered different explanations for the mechanism by which temperature affects the population. Cushing (1982) observed that all correlations of population characteristics with temperature are unlikely to be explained in the same way.

Analysis of April and May temperature data along three sections which cross the Laurentian Channel (Fig. 1) shows the process of decay of the cold surface layer and the stratification of the water masses into three layers (Fig. 10), similar to the features that were described by Lauzier *et al.* (1957). In April, the cold layer (≤0° C) to a depth of about 100 m extends across the entire section in each case, with the highest temperatures (4° to 5° C) in the deepest parts of the Channel. In May, the cold layer shrinks in size to form an intermediate cold core at 50–100 m over the central part of the Channel. The rate of shrinkage of the cold layer

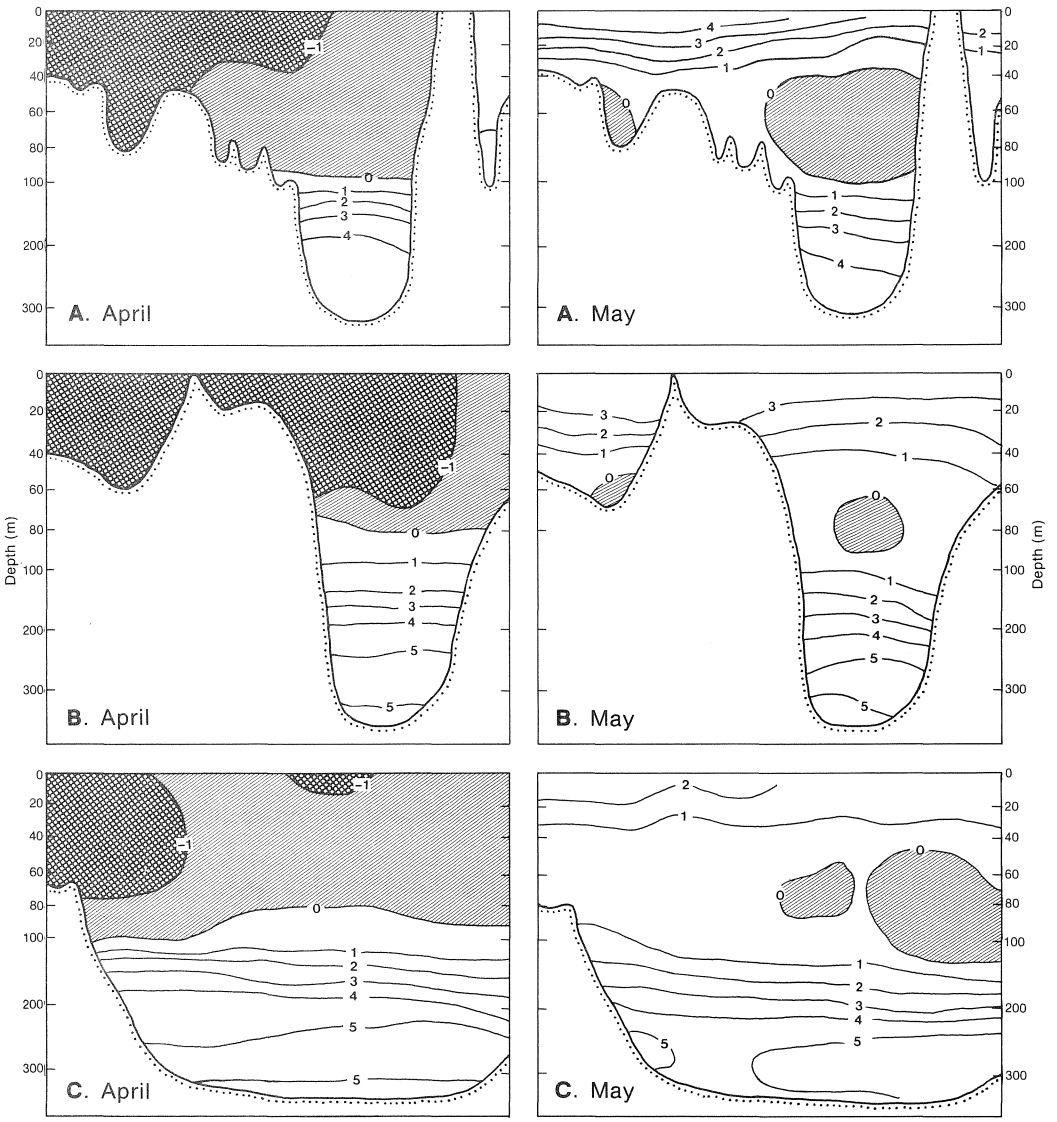

Fig. 10. Mean temperature profiles in April and May (1965–84) on Sections A, B and C (Fig. 1), showing shrinkage of the upper cold water (<0° C) to form a cold intermediate layer.

depends on the degree of spring warm-up, which in turn is influenced by the rate of freshwater run-off and wind direction (Lauzier *et al.*, 1957). It is hypothesized that the herring which overwinter in deep water along the Laurentian Channel remain there until the volume of intermediate cold water has decreased in size sufficiently to allow the spring-spawners to approach the spawning grounds in the southern Gulf of St. Lawrence without swimming through the cold-water barrier.

Seasonal movements of fish in response to temperature changes have been reported by many researchers. Templeman and Hodder (1965a, 1965b) found that haddock (*Melanogrammus aeglefinus*) retreated from the shallow areas of Grand Bank and St. Pierre Bank in late autumn, as water temperatures declined below about 2° C, and overwintered along the southwestern slopes of these banks in 150–275 m where near-bottom temperatures were between 2.5° and 9.0° C. Return to the bank plateaus in late spring and early summer coincided with gradual warming of the water in these shallow areas. Lear *et al.* (1986) examined the factors which affect the inshore fixed-gear fishery for Atlantic cod (*Gadus morhua*) in Labrador and eastern Newfoundland waters, including the effects of variations in the flow of the Labrador Current on the seasonal movements of cod. They postulated that the proportion of cod moving across the thermal barrier in the cold intermediate layer of the Labrador Current decreases as the thickness of the cold-water core increases or the temperature decreases.

Catch records of purse seiners in the 1960's and early 1970's indicated that occurrence of large concen-

trations of herring along the southwestern edge of the Laurentian Channel just before the appearance of spring-spawners on the Magdalen Islands spawning grounds and of autumn-spawners on the Magdalen Shallows in early spring. Tagging and other studies have shown that many of these herring overwintered in the deepwater inlets of southwestern Newfoundland while others overwintered along the southwestern edge of the Laurentian Channel east of Cape Breton Island (Winters, MS 1970; Iles and Tibbo, 1970; Hodder and Parsons, 1971). Analysis of purse-seine catches in the southwestern Newfoundland winter fishery (Hodder, 1969, 1971) showed a westward progression of the fishery toward Cabot Strait from January to March. In early April, the herring concentrations disappeared from the Newfoundland side of the Laurentian Channel and appeared a week or two later on the southwestern edge of the Channel in the vicinity of Magdalen Islands, where a short but intense fishery occurred. Presumably, the subsequent dispersal of these concentrations, to inshore spawning grounds in the case of spring-spawners and to summer-feeding areas in the case of autumn-spawners, coincided with increased water temperatures and shrinkage of the cold water layer.

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