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SEASONAL DISTRIBUTION OF LARVAL HERRING

(CLUPEA HARENGUS HARENGUS L.) IN THE

GEORGES BANK-GULF OF MAINE AREA FROM

1962 to 1970

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ABSTRACT

This study reports observations made on the seasonal distribution of larval herring in the Western North Atlantic from November 1962 through April 1970. It summarizes observations made during all months of the year except January and provides a more complete picture than previous studies conducted in autumn, winter, and spring of the 1950's. The seasonal distribution of larval herring from the autumn through the spring (combined with maturity, meristic and biochemical studies of adult herring in the 1960's) provides evidence of at least three discrete major spawning areas in the Western North Atlantic: Georges Bank, coastal Gulf of Maine and Nova Scotia. The presence of a clockwise gyre on Georges Bank retains the larvae on the Bank. The presence of a counterclockwise current in the coastal Gulf of Maine retains the larvae in these waters and the circulation off the coast of Nova Scotia results in the larvae remaining close to the spawning site or being carried into the Bay of Fundy.

INTRODUCTION

This paper covers the seasonal distribution of larval herring (Clupea harengus harengus L.) in the Georges Bank-Gulf of Maine area from 1962 through 1970. Studies in the 1950's on the distribution of herring larvae of the Western North Atlantic (Tibbo, Legare, Scattergood, and Temple, 1958; and Tibbo and Legare, 1960) covered only the autumn and winter, although Tibbo et al. (1958) mention the capture of herring larvae in April 1955 by the T. N. Gill from Penobscot Bay, Maine. Tibbo et al. (1958) reported that the abundance of newly hatched larvae in the plankton collections of the 1950's provided evidence that major spawning occurred on Georges Bank, along the southern coast of Nova Scotia and on a lesser scale along the inshore waters of the Gulf of Maine. Tibbo and Legare (1960) reported that almost 90 percent of the larvae taken in plankton tows in October and November were found chiefly on the Northern Edge of Georges Bank and in the Bay of Fundy. Marak and Colton (1961), Marak, Colton and Foster (1962) and Marak, Colton, Foster and Miller (1962), in their studies of fish eggs and larvae in the Georges Bank-Gulf of Maine area provide information on the distribution of herring larvae in the spring. They collected herring larvae in March, April and May from Georges Bank, Gulf of Maine and Nova Scotia (Bay of Fundy) areas. Boyar (1966 and 1970) presented preliminary reports on the distribution and abundance of larval herring on Georges Bank and adjacent waters from September through June. The present investigation provides a more complete picture of the seasonal distribution of herring larvae since we have data for all months of the year except January.

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Tibbo et al. (1958) postulated that spawning on Georges Bank could contribute herring to the waters of coastal Gulf of Maine. Tibbo and Legare (1960) stated that "the drift of larvae from the spawning grounds as indicated by increasing size and distribution of nontidal drift surface currents suggested that the Bay of Fundy herring stocks are chiefly from the Nova Scotia spawning." Studies with drift bottles suggested that the progeny of the Georges Bank spawning would be carried south, east and west but not north during late autumn and early winter (Bigelow, 1927; Day, 1958 and Bumpus, 1960). Bumpus (1960) indicated there would be little possibility for surface drift to carry larvae from Georges Bank to the Bay of Fundy. Colton and Temple (1961) stated that on the basis of the nontidal drift, it would be unlikely that larvae from Georges Bank would contribute to the coastal fishery for juvenile herring in the Gulf of Maine. In general, the evidence from previous studies was that the ultimate fate of the larvae was not known. Although detailed analysis of the origin of juvenile herring in the Georges Bank-Gulf of Maine area is beyond the scope of this paper, we believe that the data indicate that populations of herring, from Georges Bank, the coastal Gulf of Maine, and Nova Scotia are discrete.

METHODS

In 1962 personnel of the Bureau of Commercial Fisheries Biological Laboratory, Department of the Interior (now National Marine Fisheries Service, Department of Commerce) Boothbay Harbor, Maine, initiated surveys to obtain additional information on the distribution of larval herring in the Georges Bank-Gulf of Maine area. Oblique plankton tows of 15 minutes (5 minutes at 20 meters, 5 minutes at 10 meters and 5 minutes at the surface) were made with a one-meter #0 mesh net. Post-larvae obtained in 1967 and 1969 were not collected by a plankton net, but were found meshed in the twine of the otter trawl. Larvae were collected from autumn through spring from 1962 through 1969. Vessel time was limited and we were, therefore, unable to study the temporal distribution of larvae for every year. Because the cruises were designed primarily for other research, plankton tows were made only when time was available. We were, consequently, unable to duplicate plankton stations from year to year for a specific month. In the autumn the majority of the plankton tows were made on the northern part of the Bank. In April and June 1966 and October 1964 and 1967, in addition to sampling various parts of Georges Bank, we made transects from the northern part of the Bank to the coast of the Gulf of Maine.

In 1967 personnel at the Bureau of Commercial Fisheries Biological Laboratory, Department of the Interior (now National Marine Fisheries Service, Department of Commerce) in Woods Hole, Massachusetts commenced studies to determine the distribution of fish eggs and larvae in the Georges Bank-Gulf of Maine area. In all but one cruise (Posgay and Marak, 1967) they used 8-inch bongo nets towed for 5 minutes at 50 meters, 5 minutes at 25 meters and 5 minutes at the surface. Data on the distribution of the herring larvae obtained during the Woods Hole cruises were from the autumn through the spring of 1967 to 1970. The cruises covered the area from Cape Hatteras, North Carolina, northward to Georges Bank, into the Gulf of Maine, up to the Bay of Fundy and then to the southern tip of Nova Scotia. In addition, during some months only, special cruises were made and these were concentrated on the northern and central part of Georges Bank in a 50 X 50 mile square which included the Northern Edge, Northeast Peak and Winter Fishing Ground of the Bank.

The collecting gear used in the studies of the 1950's were Hardy continuous plankton recorders and one-meter nets. These investigations covered the entire area of Georges Bank, coastal and central Gulf of Maine, the southern tip of Nova Scotia and the Bay of Fundy.

The areas concerned in this paper are shown in Figure 1. Since various types of gear, depths at which the gears were towed and the time of day at which the tows were made were not similar in the studies by the two laboratories, we have made no attempt to present a statistical analysis of the relative abundance of herring larvae. We have merely shown the stations where larvae were and were not obtained, although at the stations where larvae were obtained, we have presented a rough measure of relative abundance.

DISTRIBUTION OF LARVAL HERRING

Results:

Three major spawning areas have been reported for the Georges Bank-Gulf of Maine area; namely, Georges Bank, coastal Gulf of Maine and Nova Scotia (Boyar, 1968 and 1970). The areas where ripe and running herring (gonadal stage VI) have been obtained since 1961 (Boyar, unpublished data) are shown in Figure 2. The dates, stations showing absence, presence, and range in number of larvae by month and year are shown in Figures 3 through 11.

We obtained larvae in September 1964, 1965 and 1968 primarily from the eastern part of Georges Bank (Figure 3). We failed to obtain larval herring in September of 1963, 1966 and 1967, but this is directly related to the time of spawning. Examination of the gonads of adult herring collected by trawling in these years indicated that spawning had not yet taken place (Boyar, 1968).

In October larvae were collected at the majority of the stations where plankton tows were made (Figure 4). During our cruise in October 1964 we made a transect between Georges Bank and the coastal Gulf of Maine. Larvae were not obtained north of the Bank until we reached Jeffreys Ledge.

In November when sampling was restricted to the Bank larvae were obtained at the majority of the plankton stations (Figure 5). When the entire Georges Bank-Gulf of Maine area was sampled, larvae were obtained from various stations throughout the three areas, but only a few were obtained from the central part of the Gulf of Maine (three in 1965 at a station between 50 miles northwest of Cultivator Shoals and 50 miles east of Cape Cod, Massachusetts; and four in 1969; one at a station approximately 30 miles northwest and north of the Bank and 3 at a station approximately 35 miles north of the Northern Edge. In most areas larvae were obtained in close proximity to their specific spawning areas; namely, Georges Bank, coastal Gulf of Maine and Nova Scotia.

In December larvae were collected at the majority of the plankton stations, but none from the one tow made at the station in the coastal Gulf of Maine (Figure 6). The few larvae that were obtained north of the Bank were taken approximately 20 miles northwest of the northern part.

In February larvae were obtained from a few stations along the Northern Edge of Georges and from most of the stations on the Winter Fishing Ground and slightly southward. No larvae were obtained from the stations east of latitude $66^{\circ}10'W$. (Figure 7).

In March larvae were obtained throughout the various parts of the Georges Bank-Gulf of Maine area (Figure 8). The few larvae from the central part of the Gulf of Maine were collected at 2 stations (one at each) between 25 miles north of Georges Shoals and 60 miles east of Stellwagen Bank.

In April larvae were collected throughout various parts of the Georges Bank-Gulf of Maine area. The larvae were most abundant in the north and central eastern part of Georges Bank (Figure 9).

In May larvae were concentrated between latitudes 67° and $66^{\circ}W$. Larvae were not collected east of $66^{\circ}W$. (Figure 10).

In June plankton tows were made only on the Bank. In the years in which larvae were obtained, they were collected from various parts of the Bank. In 1966 sampling was conducted primarily on Georges, but a few tows were made on a transect to the coastal Gulf of Maine (Figure 11).

In July plankton stations were restricted to the southwestern part of Georges Bank while in August sampling was conducted at several stations on Georges Bank, Gulf of Maine and Nova Scotia. No larvae were obtained; the larvae by this time had metamorphosed and our plankton sampling gear was not adequate to catch them.

Discussion:

The onset of spawning on Georges Bank and in the coastal Gulf of Maine usually occurs during late August or early September. The peak of spawning is during late September or early October. Spawning decreases in intensity in November and by December and early January spawning is completed (Boyar, 1968). In Nova Scotia spawning takes place from May through December. The bulk of the spawning, however, is in September and October. Spawning during the spring and summer takes place on the western part of the coast.

Larval herring are found in the three areas mentioned above from autumn through the spring. The collection of fewer larvae during the winter on Georges Bank (exclusive of those lost from natural mortality and predation) may be due to 1) our technique in sampling (not as extensive in the winter as during the autumn and spring, or 2) the larvae at this time of the year may be in waters deeper than 50 meters. The available data on the distributions of larval herring from September through February of the 1960's on the Bank are similar to those reported by Tibbo et al. (1958) and Tibbo and Legare (1960) for the late 1950's. The distributions of larvae in the spring of the 1960's on the Bank were similar to those found by Marak et al. (1961), Marak, Colton and Foster (1962) and Marak, Colton, Foster and Miller (1962).

The distribution of larvae during the autumn is well defined except during September 1963, 1966 and 1967 when we failed to obtain larvae; the majority of the herring taken during that month were in late stage V of gonadal development. Tibbo et al. (1958) reported similar information for September 1957 and stated that the absence of herring larvae on Georges Bank at that time of the year was either because the herring had not spawned or because the eggs of herring that had spawned had not hatched. The majority of larvae from the spawnings along the northern part of the Bank remain in close proximity to the spawning site for a few days and then become dispersed, many being carried by the drift in a southerly direction towards the southeast part of the Bank. In October and November when larvae are found dispersed throughout various parts of the Bank, their distribution suggests that they have been carried clockwise by the current. Larvae found dispersed throughout the Bank in December further suggest that those from the spawnings on the northern part are carried in a clockwise manner. Some of the larvae, however, found on the southern part of the Bank in December may be the offspring from the minor spawnings in this area. The few larvae found between Nova Scotia and the northern part of the Bank may be from the minor spawnings on Brown's Bank (Tibbo et al., 1958) or result from an occasional breakdown in the southerly drift away from Georges, while those found in the middle of the Gulf of Maine are either from the occasional breakdown in the southerly drift away from the Bank or are from spawnings in the Gulf of Maine, itself. Our findings of larvae for these months are similar to those of Tibbo et al. (1958) for 1956 and 1957. The distribution of larvae on various parts of the Bank and off Cape Cod, Massachusetts in the 1960's is similar to that found by Tibbo et al. (1958) for the same areas in 1956 and 1957. In February larvae are found throughout the Bank. Although during this month we collected larvae only from the Northern Edge, Northeast Peak and Winter Fishing Ground, Tibbo et al. (1958) did obtain larvae from the southwest part in 1957 and in 1958 they obtained larvae from the Northern Edge and other parts of the Bank, even though they failed to obtain larvae from the Northern Part of the Bank. In March the distribution of larvae on the Bank is similar to our findings for November and December and also agree with the findings of Marak et al. (1961), Marak, Colton and Foster (1962) and Marak, Colton, Foster and Miller (1962).

The distribution of larvae in the spring in the three areas is as well defined as the distribution of the larvae during the autumn. The larvae are, however, still at the mercy of the drift on the Bank, but may be now large enough to maintain their position, at least for a short time. Our findings of larvae in April from the three areas differ from the data of Marak et al. (1961), Marak, Colton and Foster (1962), and Marak, Colton, Foster and Miller (1962) in that we obtained larvae from Georges Bank, coastal Gulf of Maine and Nova Scotia while they sampled the three areas and collected larvae only from Georges Bank. In May we obtained larvae from the northern and central eastern parts of the Bank only, although we made plankton tows in several other parts of the Bank. In June we obtained larvae from several parts of the Bank. We made no attempt to sample the coastal Gulf of Maine and Nova Scotia, but Marak et al. (1961), Marak, Colton and Foster (1962), and Marak, Colton, Foster and Miller (1962) did collect larvae from these areas.

Larval herring are still present in large numbers in late April and May on Georges Bank and can be occasionally found as post-larvae in June. In July and August the fish are now brit size and our plankton sampling gear is not adequate to catch them. Since larval herring and juvenile herring of comparable length are collected in the inshore waters of the Gulf of Maine and Nova Scotia at the same time of the year (Graham and Boyar, 1965 and Das, 1968), it seems likely that the major distribution of larval herring of Georges Bank is restricted to the Bank and its contiguous waters.

Our interpretation differs from that of Das (1968) who stated that based on the work of Tibbo et al. (1958) and Boyar (personal communication), larvae spawned in late autumn on the Northern Edge of the Bank would "be carried across Brown's Bank northward toward the southern coast of Nova Scotia in the following spring" and that in the spring there would be "a contribution of herring larvae from the northern Georges Bank area to the herring population in the Fundy area." Larvae found in the middle of the Gulf of Maine could have come from spawnings along the coasts of Massachusetts, New Hampshire and Maine (Figure 2). Tibbo (1968) reported that there may be cases in which larvae from Nova Scotia spawnings might be carried, because of the open circulatory system, southward along the coast of Maine as far as Cape Cod, Massachusetts and beyond.

Data on larvae collected in the 1950's and 1960's lend support to the hypothesis that there are three major spawning areas in the Georges Bank-Gulf of Maine area (Boyar, 1968). Parasitological and serological studies (Sindermann, 1959), meristic studies (Anthony and Boyar, 1968) and biochemical studies (Ridgway, Lewis and Sherburne, 1970) of herring also indicate the possible discreteness between the populations of herring of Georges Bank and the coastal Gulf of Maine. Ridgway et al. (1970) demonstrated that there are definite differences in gene frequencies between Gulf of Maine-Nova Scotia herring and herring from Georges Bank. Their findings imply that the larvae from the Bank do not contribute to the Gulf of Maine-Nova Scotia stocks. Our findings of large numbers of larvae on Georges Bank and the findings of Graham and Boyar (1965) and Graham and Venno (1968) of large numbers of larvae from the coastal Gulf of Maine plus the virtual absence of larvae between the two areas from September through May-June suggests that the resulting larvae from spawnings on the Bank and along the coastal Gulf of Maine do not mix significantly. Tibbo and Legare (1960) suggested that the larvae found in the Bay of Fundy are primarily from Nova Scotia spawnings. We question the significance of the contribution of larval herring from the Northern Edge of Georges Bank to the Bay of Fundy, as reported by Das (1968). We believe the larvae of Nova Scotia either mature off Nova Scotia or in the Bay of Fundy and contribute to the future stocks of juvenile herring in these waters and possibly to the stocks of juvenile herring along the coast of Maine and perhaps southward. It appears that because of the counterclockwise circulation in the coastal Gulf of Maine the majority of the larvae from the central and western part of the Gulf of Maine (November and March, Figures 5 and 8) are the offspring from the numerous spawnings along the coast (Figure 2). Although it is also possible, due to a breakdown in this circulation, that larvae could have come from Nova Scotia as postulated by Tibbo (1968).

The majority of the larvae obtained in the Georges Bank-Gulf of Maine area were from stations where the depth was 50 fathoms or less. Although most of our effort was concentrated on Georges Bank where the depth is 70 fathoms or less (exclusive of the Northeast Peak), most of the larvae obtained from the central and coastal Gulf of Maine and Nova Scotia were also obtained at depths of 50 fathoms or less.

Tibbo et al. (1958) reported that more larvae were obtained at night than during the day. Brawn (1960) and Colton, Honey and Temple (1961) presented data that clearly indicate that larval herring exhibit vertical migration. The question remains as to whether the larvae during the daytime are close to the bottom (as are adult herring) and attempt to use the bottom as a visual reference point for maintenance against the current. Larvae obtained in the early autumn would be unable to stem the prevailing currents. Bishai (1960) demonstrated that the critical current velocity for yolk-sac larvae would be between 0.58 and 1.03 cm. per second. Larvae of the size obtained during the winter and spring would also be unable to stem any current for a prolonged time (Rosenthal, 1968). The post-larvae we obtained on the Bank, found meshed in the cod end of the otter trawl lined with fine mesh, were probably collected from near or on the bottom. They were caught in waters of 30 fathoms or less and our meter net tows, although made only to a depth of 20 meters, did not catch any. Even though the post-larvae were at the bottom, they too would be at the mercy of a current, although there could be occasions when they could stem certain minimal currents for short periods (Boyar, 1961).

Questions regarding the vertical migration of larval herring and whether they can maintain their position on the bottom remain unanswered. Boyar (1961) demonstrated a direct relationship between the size of herring (juveniles) and their ability to maintain their position against various water velocities. Herring of 60 to 79 mm. were able to maintain their position against a current of 85.3 cm./second for no more than 30 seconds. Juvenile herring of 200 to 220 mm. were able to maintain their position against a current of 140.2 cm. per second for no more than 30 seconds. Yet post-larvae as well as juvenile herring have been obtained in waters of 30 fathoms or less: at least on Georges Bank. Juvenile herring (2 and 3 years old) have been collected from Little Georges in 1962, from Cultivator Shoals in 1964, from Little Georges and Cultivator Shoals in 1965 and from Cultivator Shoals in 1967 (Boyar, 1968). The juvenile herring occur primarily in shallow waters; all collections were made in depths of 20 to 30 fathoms. Gill net sets made in deeper waters of the Bank failed to yield herring. Apparently post-larvae eventually find their way to the shallow waters of the Bank and contiguous waters where they eventually develop into juvenile herring.

Muench (unpublished manuscript based on data of sea bed drifters set by Woods Hole Oceanographic Institute) has reported that the residual currents on the bottom on Georges Bank were similar to those on the surface in May as reported by Bumpus and Lauzier (1965), i.e. on the order of 3 nautical miles per day. Bumpus (personal communication) stated that the tidal current at the bottom on the Northeast Peak was 9/10 as fast as the surface tidal current. It is reasonable to assume (Bumpus, personal communication) that this condition prevails over all of the Bank. Data on the strong tidal currents (30 to 100 cm. per sec.; Tidal Current Tables, 1962-1970 inclusive) suggests that the current on the bottom and surface would be too great for larvae to swim against, and that their net movement would be largely controlled by the current, thus the clockwise gyre on Georges Bank will retain the larvae on the Bank. Since larvae and post-larvae are found in large numbers on the Bank, in large numbers in the coastal Gulf of Maine (Graham and Boyar, 1965; Graham and Venno, 1968) and in large numbers in Nova Scotia (Das, 1968) and the acknowledgement of three discrete spawning populations in the Georges Bank-Gulf of Maine area is adequate evidence of this fact. Therefore, it would seem unlikely that larvae would leave the Bank in the fall to return in the spring. Such a phenomenon would suggest a voluntary migration. Larvae for all practical purposes are trapped in the gyre on the Bank and this would explain the "enigma" discussed by Colton and Temple (1961).

During our cruises in March and April 1970 we obtained larvae southwest of Martha's Vineyard and approximately 50 miles south of Nantucket Island. Herring larvae have been obtained off the coasts of Massachusetts (Martha's Vineyard) southward to Maryland-Virginia (Kendall, A., manuscript in preparation). The larvae from the above mentioned areas and those that we obtained from Hudson Canyon (January, 1971) because of the circulatory system, would appear to be the offspring of spawners from the Nantucket Shoals area.

SUMMARY

1. Investigations were conducted on the distribution of larval herring in the Western North Atlantic for 1962 through 1970.
2. Statistical quantitative analysis of the relative abundance of larvae was not possible since various types of gear were used.
3. Larval herring were collected from September through June (exclusive of January).
4. We believe that the distribution of larval herring in the study area indicates three discrete spawning populations for the following reasons:
 - a. Yolk-sac larvae were found in close proximity to known spawning sites on Georges Bank, the coastal Gulf of Maine and Nova Scotia.
 - b. The presence of a clockwise gyre on Georges Bank figuratively traps the larvae on the Bank and retains them there. Larval herring spawned along the western and central part of the coastal Gulf of Maine, because of the circulatory system, appear to be restricted to these waters although on occasion some may drift into the middle of the Gulf of Maine. The majority of larval herring from Nova Scotia spawnings either remain in close proximity to the spawning grounds, because of the circulatory system, or are carried in high concentrations into the Bay of Fundy. Some of the larvae from the Bay of Fundy, however, undoubtedly drift to the eastern part of the coastal Gulf of Maine where they mix with the larvae from local spawnings and they may also be carried as far southward as Cape Cod, Massachusetts.
 - c. Our data on the distribution of larval herring agree with the results of meristic and biochemical studies on the discreteness of the populations of herring from the three areas.
5. Yolk-sac larvae were collected from Georges Bank from September through December. The extended spawning season in some years also occurs in the coastal Gulf of Maine and may on occasion occur in Nova Scotia.
6. Post-larvae living on the Bank appear to prefer shallow waters.

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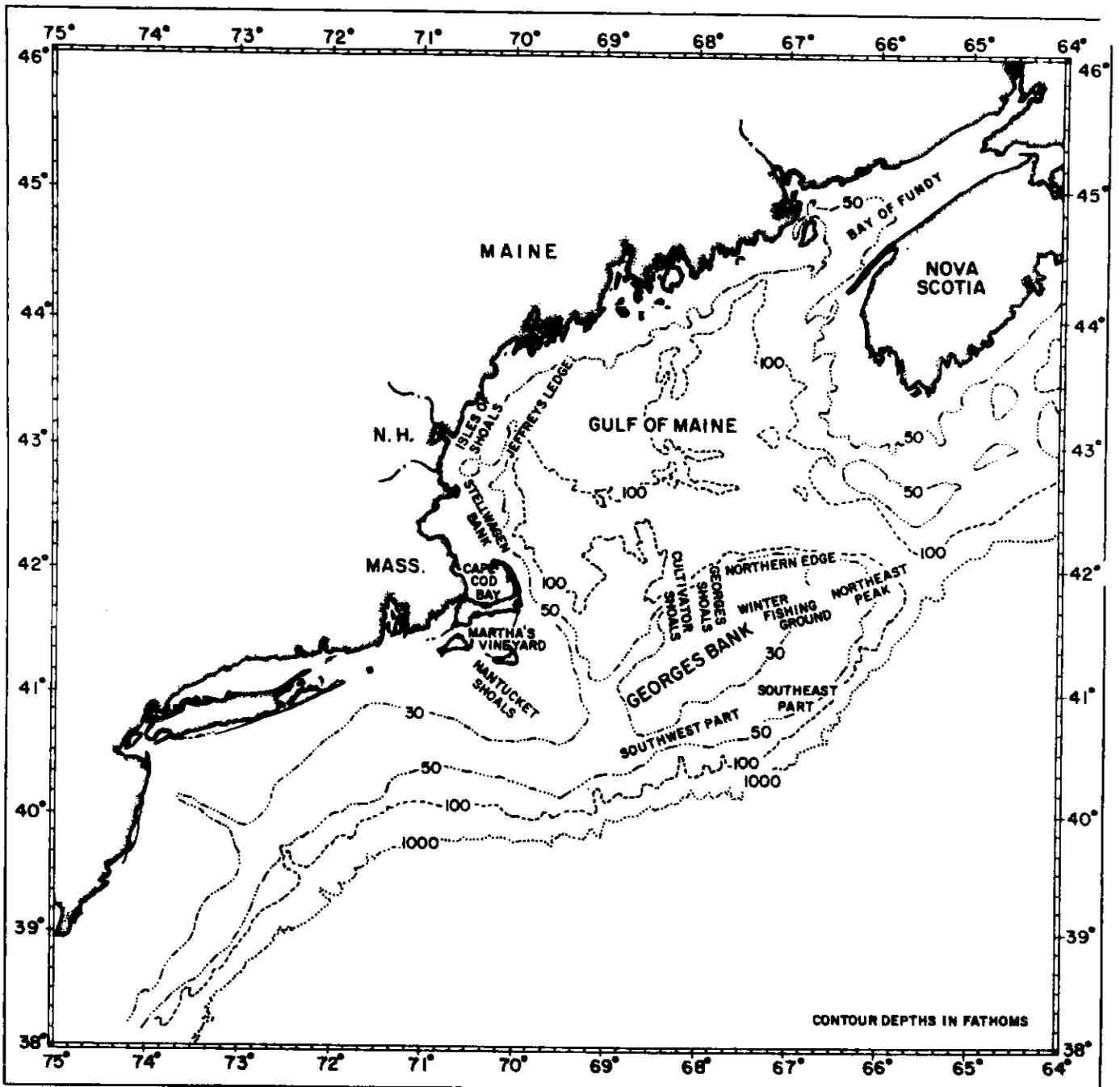


Figure 1. Chart of Georges Bank, Gulf of Maine and Nova Scotia.

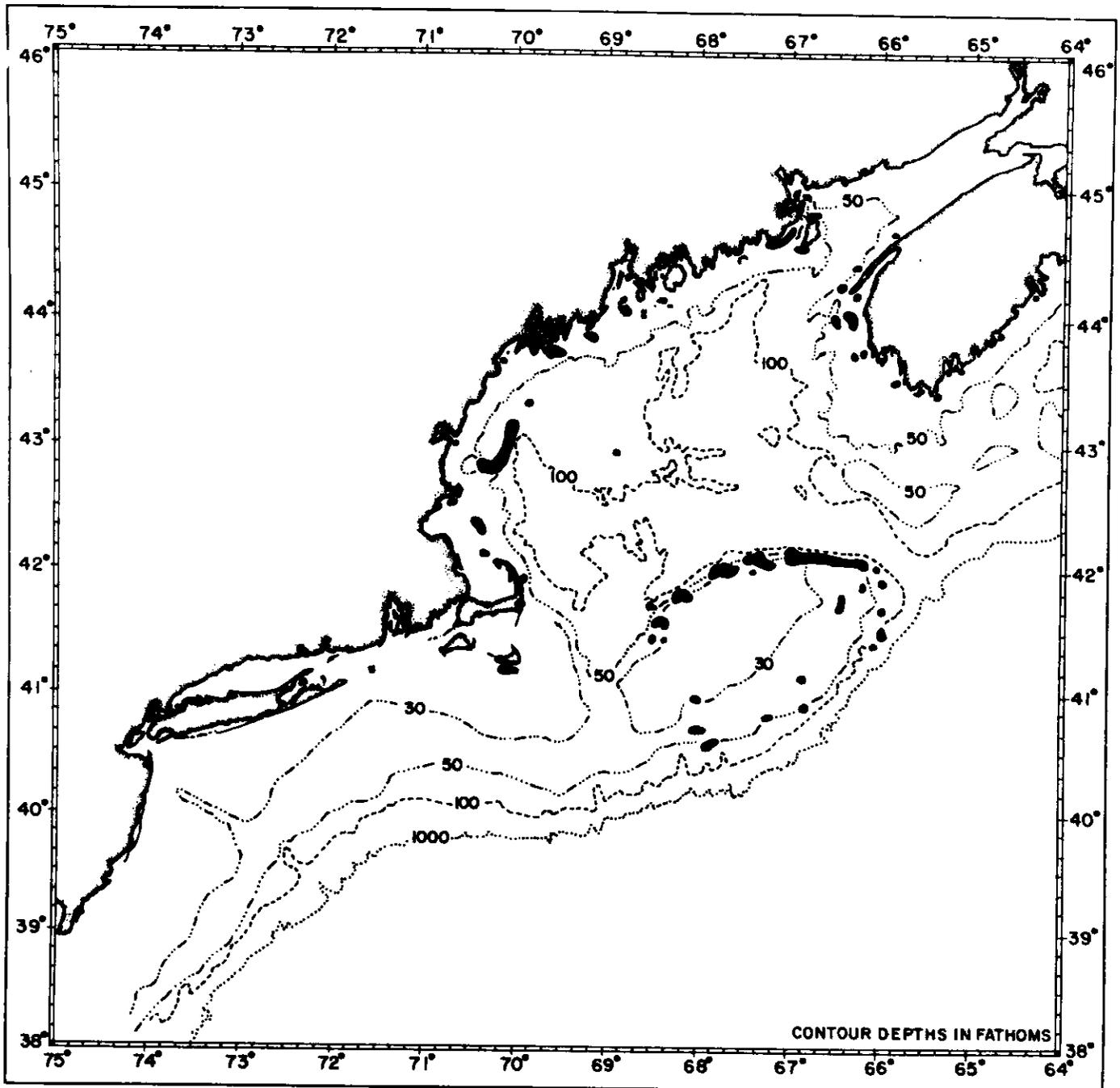


Figure 2. Spawning areas of sea herring (based on collections of adults in stage VI of gonadal development) in the Georges Bank-Gulf of Maine area.

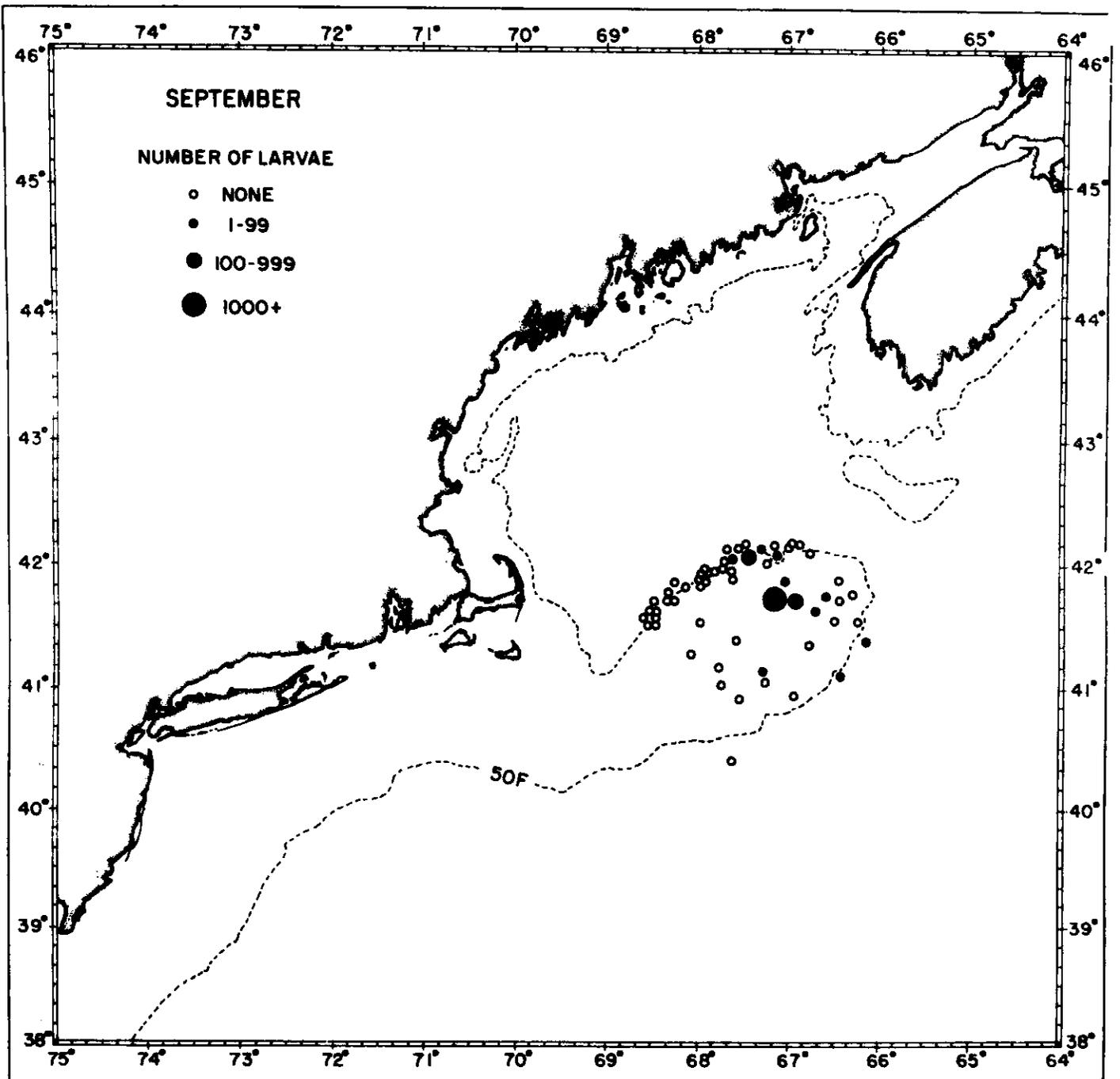


Figure 3. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in September 1963-1968.

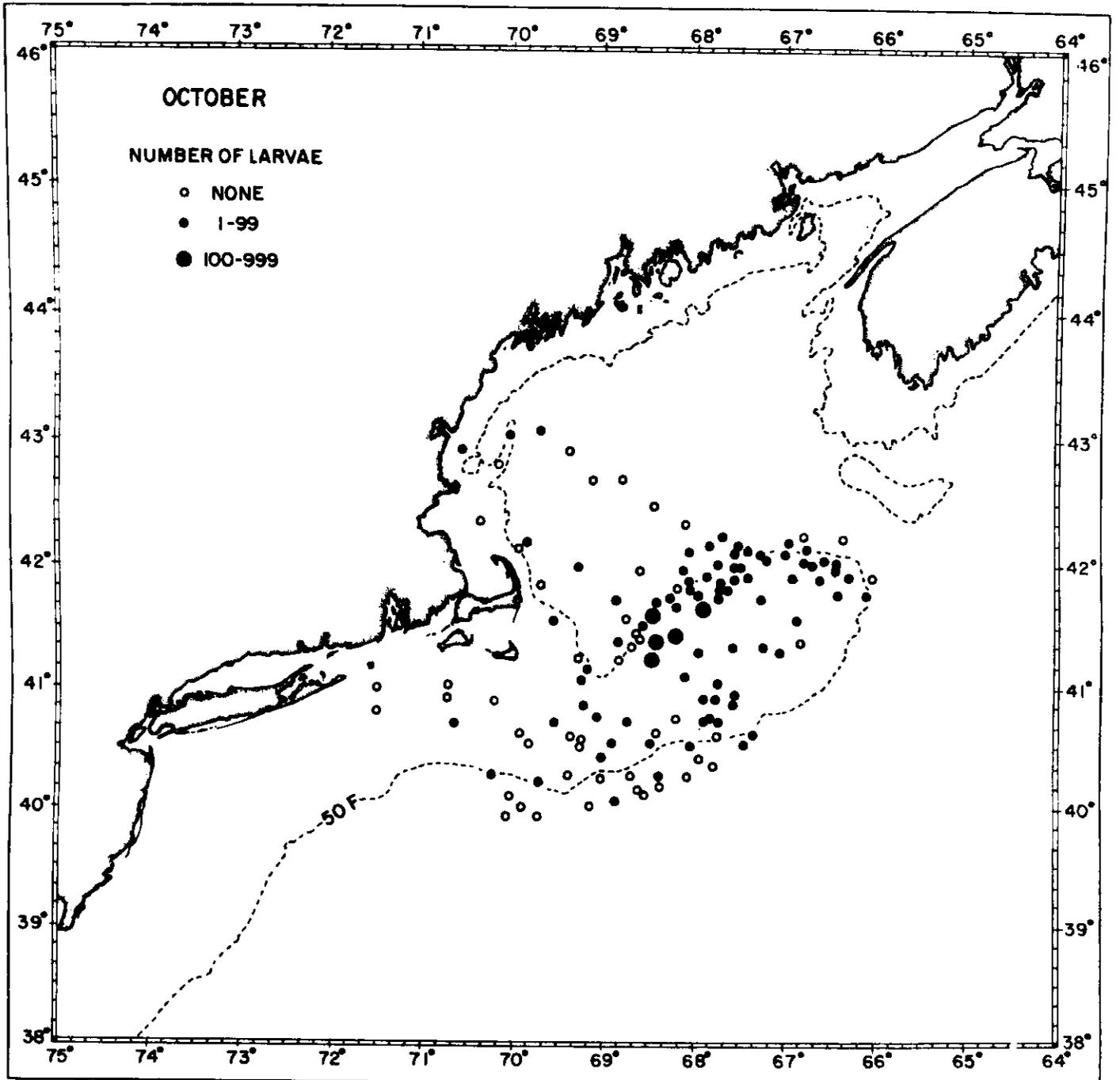


Figure 4. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in October 1964 and 1966-1969.

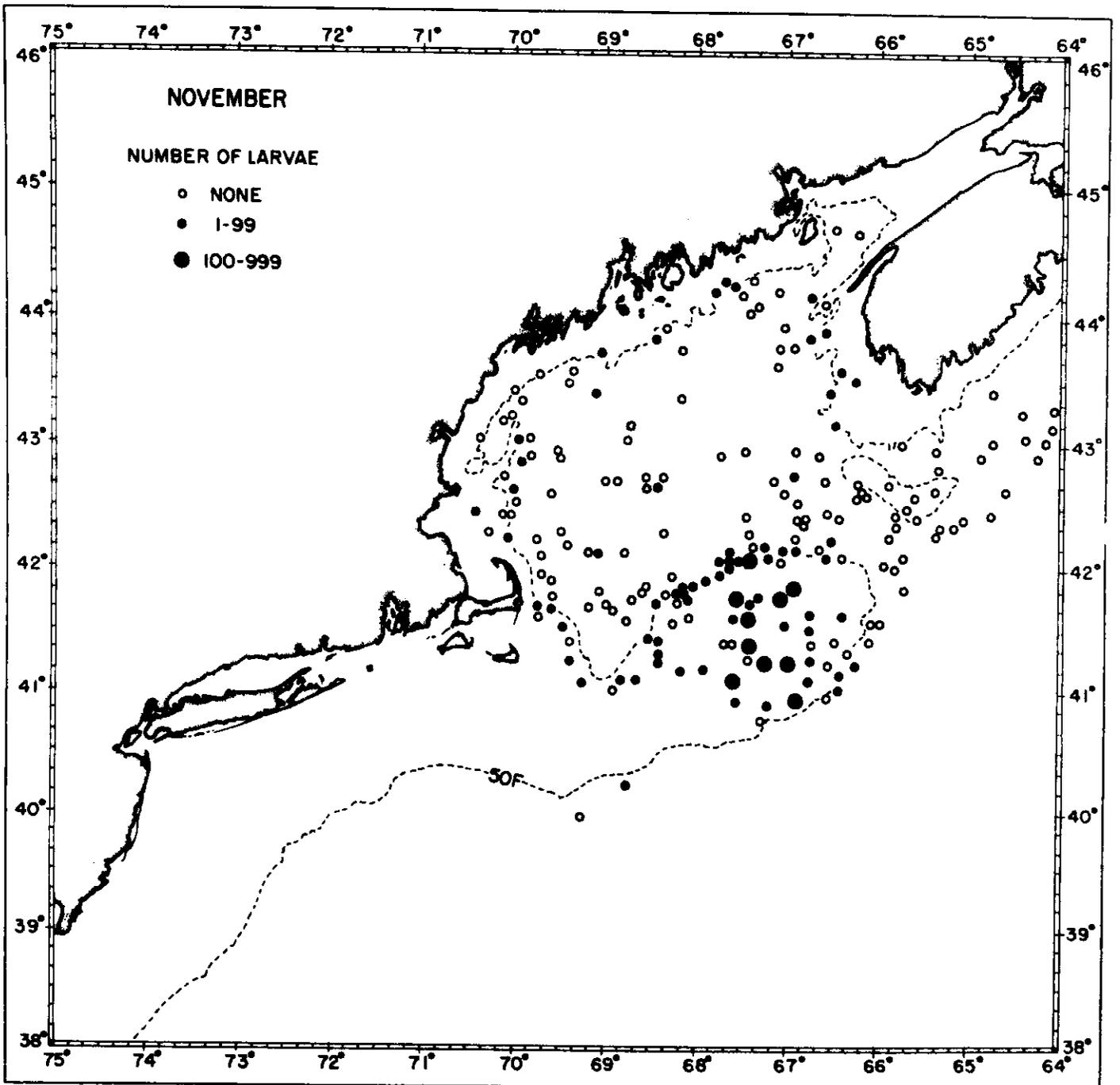


Figure 5. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in November 1962-1965 and 1968-1969.

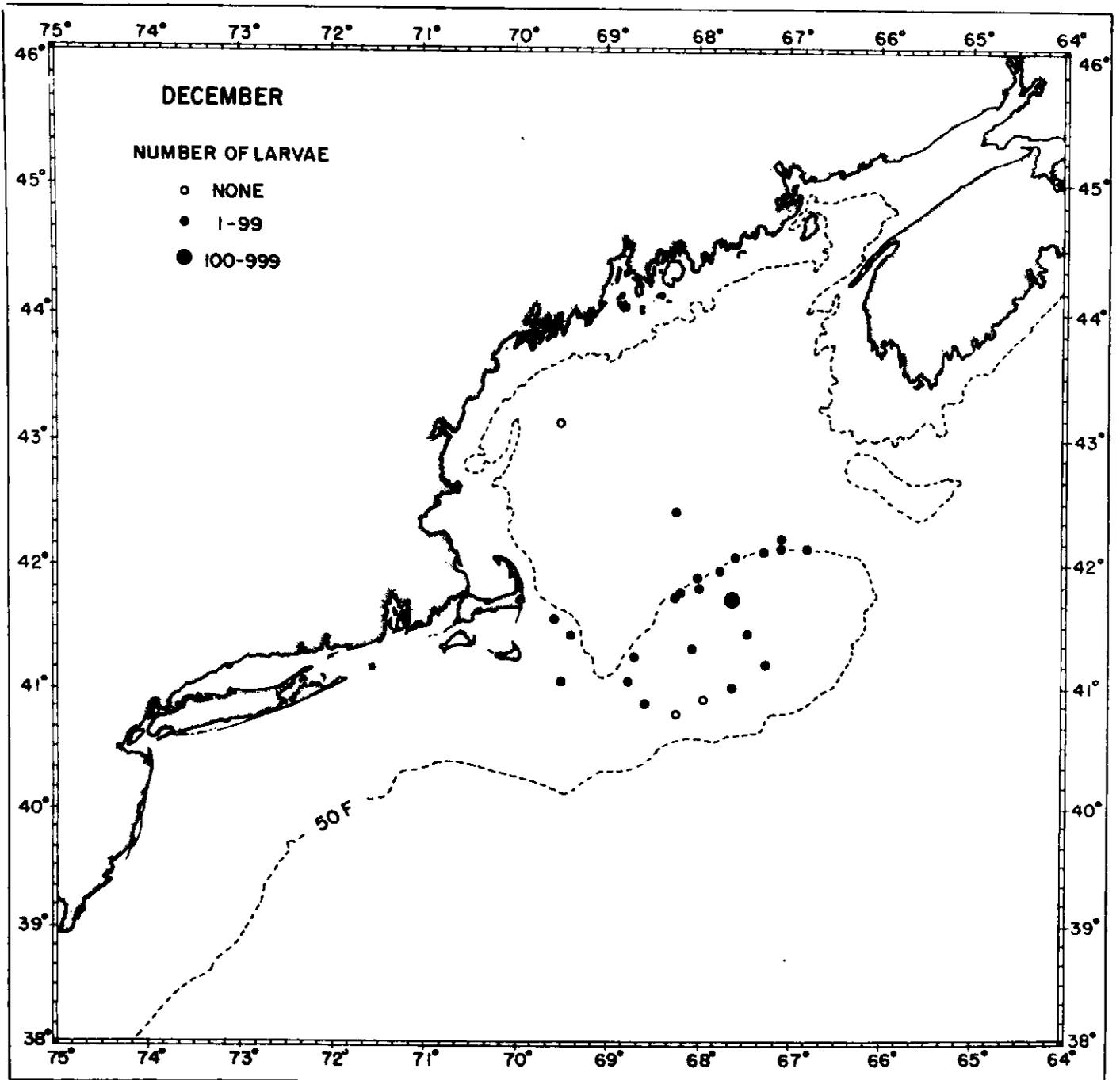


Figure 6. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in December 1962-1963.

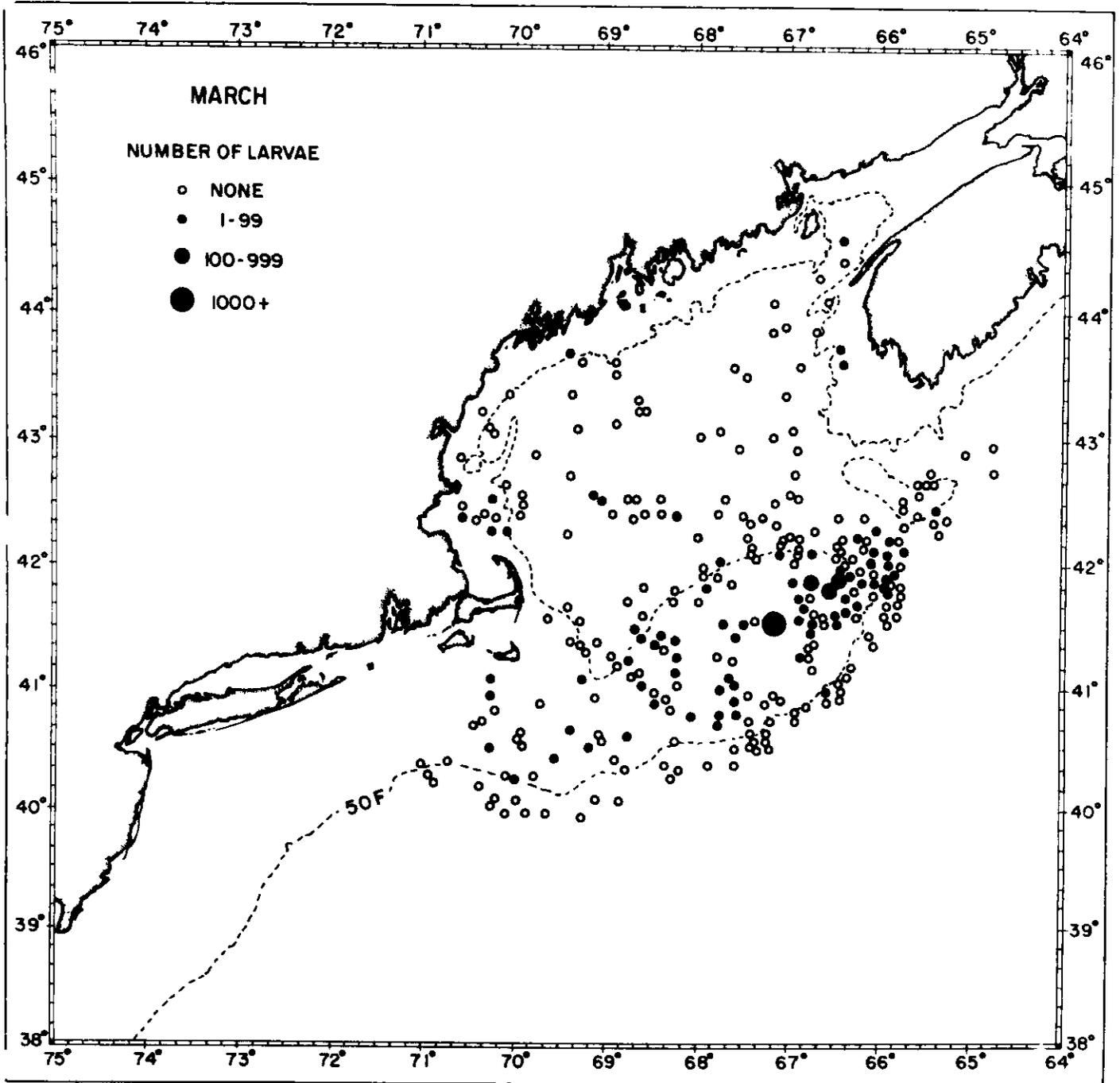


Figure 8. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in March 1967-1970.

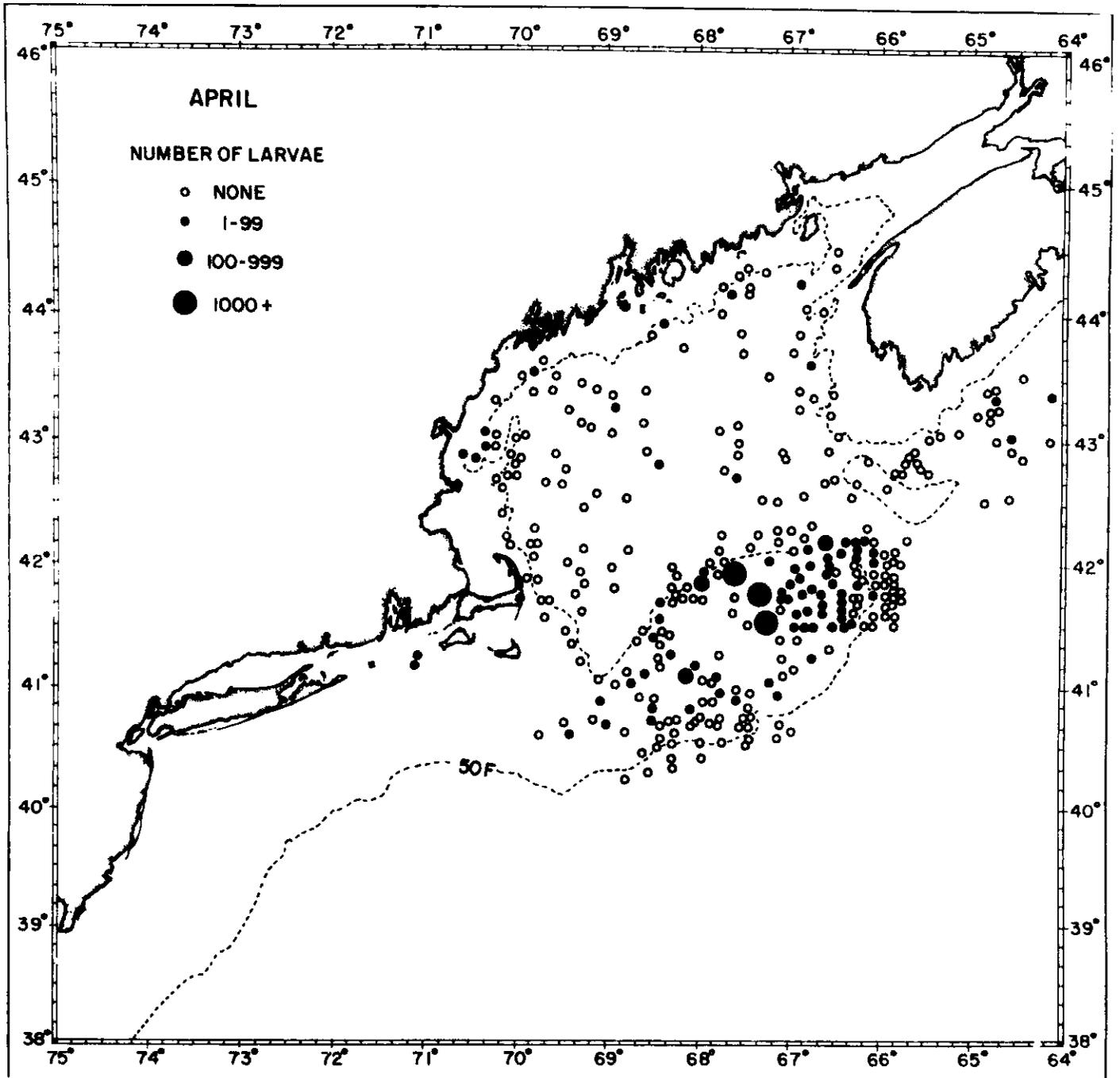


Figure 9. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in April 1965-1970.

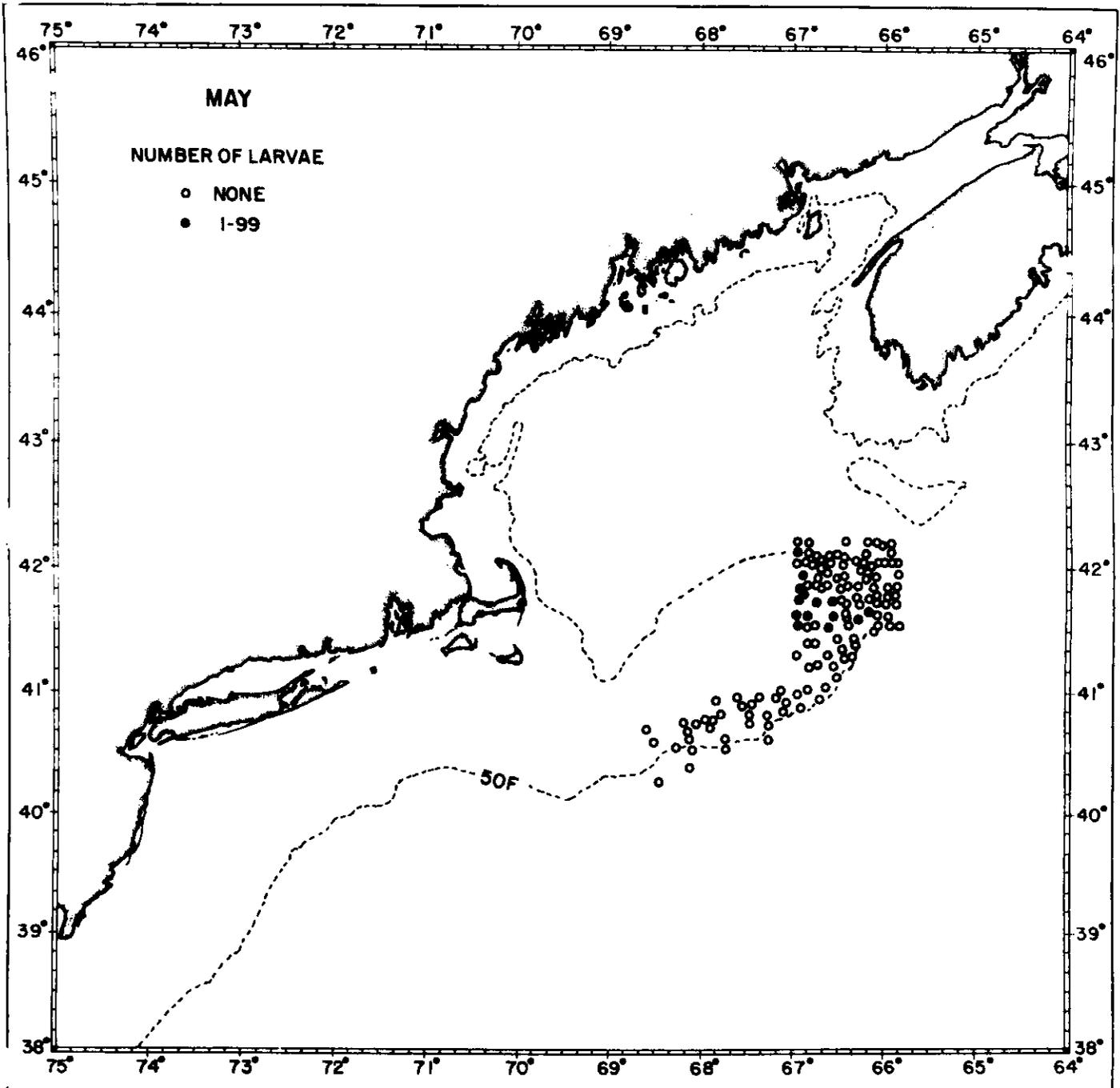


Figure 10. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in May 1968-1969.

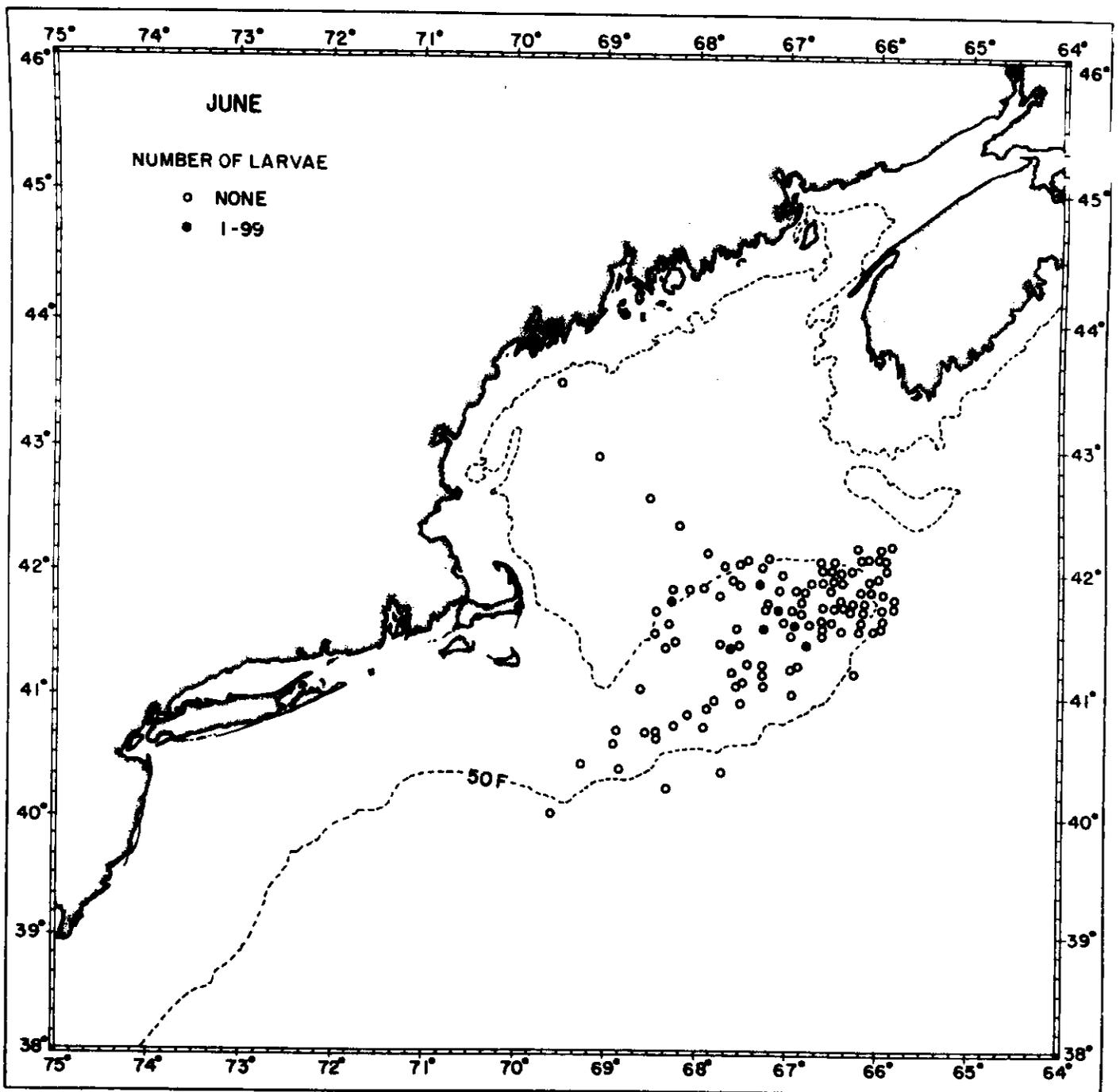


Figure 11. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in June 1963, and 1965-1969.