Surface Oil Spill Trajectory Modelling for Georges and Browns Banks

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SURFACE OIL SPILL TRAJECTORY MODELLING FOR GEORGES AND BROWNS BANK

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ABSTRACT

Lawrence, D.J. and Trites, R.W. 1983. Surface oil spill trajectory modelling for Georges and Browns Banks. Can. Tech. Rep. Hydrogr. Ocean Sci. 29: iv + 30 p.

A simple model combining reduced wind vectors and a residual current field is applied to the Georges and Browns Bank region to simulate surface oil movement. The wind reduction factor was set at 3%. More than twenty years of offshore wind data from Sable Island and historical residual surface current data supplemented by recent direct measurements were used. From Georges Bank, the predominant movement was towards the north and northeast in summer and towards the south and east in winter. From Browns Bank the movement was similar.

Résumé

Lawrence, D.J. et Trites, R.W. 1983. Modélisation des trajectoires des déversements de mazout en surface pour les bancs de Georges et de Browns. Can. Tech. Rep. Hydrogr. Ocean Sci. 29: iv + 30 p.

Un modèle simple combinant des vecteurs réduits du vent et un champ de courant résiduel est appliqué à la region des bancs de Georges et de Browns pour simuler les déplacements en surface du mazout. Le facteur de réduction du vent a été fixé à 3%. Des données de l'île de Sable furent utilisées pour représenter les vents du large pendant une période de plus de 20 ans et des données historiques sur le courant résiduel de surface en plus de données résultant de mesures directes recentes. Du banc de Georges le déplacement prédominant s'effectuait en direction du nord et du nord-est en été et en direction du sud et de l'est en hiver. Les déplacements étaient similaires dans le cas du banc de Browns.

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I. INTRODUCTION

In recent years the Department of Fisheries and Oceans has become increasingly involved in the provision of advice and guidance to other regulatory agencies on the offshore marine environment. This has taken a variety of forms, such as the evaluation of environmental impact statements, the review of contingency plans and the assessment of some of the impacts that might result should oil spills occur as a result of offshore oil exploration/production (Longhurst, 1982). Additionally, when major oil spills occur in Canadian waters, a team of scientists is assembled both to provide immediate technical advice to those charged with protection and cleanup responsibilities, and as well to acquire new knowledge on the behaviour and impact of oil released into the ocean (e.g., the grounding and subsequent breakup of the tanker Arrow, in Chedabucto Bay, (Anon, 1970); the breakup of the tanker Kurdistan in Cabot Strait in March, 1979 (Vandermeulen, 1980)).

Most crude oils and petroleum products are less dense than sea water, so that even for an oil well blowout, most of the oil rises quickly to the sea surface. The subsequent weathering process is complex and is dependent on both the type of oil as well as the environmental conditions. In the case of crude oils, a sizable proportion of the more volatile components will evaporate into the atmosphere within a matter of days (typically approx. 25-35%). In the days and weeks following a spill a small fraction (approx. 5-10%) will become dispersed in the water column. However even after several months, the bulk of the oil still persists at or near the sea surface or along shorelines, (e.g. Spaulding, et al., 1983).

Owing to the combined action of wind, current, and turbulence, oil at the sea surface is highly mobile and within a very short period may be distributed over several thousand square kilometers of ocean (Audunson, 1980; Vandermeulen, 1980). Therefore, in assessing the areas threatened by offshore oil spills, it is of paramount importance to construct hypothetical oil spill trajectories using available oceanographic and meteorological data. In this report, we utilize a relatively simple surface oil trajectory model to investigate movement away from selected sites on Georges and Browns Banks and the eastern Gulf of Maine. Both winter and summer conditions are covered, and the possibilities of entrapment or escape and shoreline contact investigated.

II METHODS AND ASSUMPTION

In this study it is assumed that surface oil movement can be computed by vectorially adding 3% of the wind vector to that of the residual current. This is one of the most common models in use, primarily because of its simplicity (see Huang and Monastero, 1982). It is best suited for situations where oil is confined to the top several cm of the ocean (Davidson and Lawrence, 1982). It has been shown to work successfully in the case of the Kurdistan oil spill off the Nova Scotian coast (Trites, et al., 1981b). Since all models involve simplifications of the real world, it is very important to consider the various physical processes influencing the oil movement to see which can safely be neglected (Davidson and Lawrence, 1982).

(a) Wind forcing. Direct wind forcing is very important and is a key feature of the present model. It has been shown that a simple reduction factor applied to the 10 m wind works quite well and that a value of 3% is suitable for the top several cm of the water column (Davidson and Lawrence, 1982). Non-local winds produced by large-scale weather patterns can also produce motions on the shelf. These may be very complex being influenced by various topographic features as well as stratification. Large numerical models would be needed to incorporate such processes. On the short term, the resultant excursions are assumed to be small compared with the size of the area to be modelled and no attempt has been made to include them in the study. Any important long term effects would show up in the estimates of the residual current field.

(b) Tidal effects. Tidal excursions are only imporant in determining the path in detail over periods of less than a day. The non-linear interaction between the tidal currents and the bottom, resulting in tidal rectification, may contribute importantly to the net displacement of oil over longer time periods (Loder, 1980). This tidally-induced circulation has been included in the residual current fields used in the model.

(c) Inertial motions. Inertial excursions are expected to be small (less than 10 km) and intermittent and difficult to predict. Moreover, they contribute nothing to the mean motion, and therefore they have not been included in the model.

(d) Boundary forcing. The only major current intruding into the area is the Nova Scotia coastal current. This is well represented in the resolution of the residual current grid. Large eddies from the Gulf Stream can cause large effects (Smith, 1983a) but their frequency and timing is random. Thus they have been neglected for the purposes of this study.

(e) Diffusion. Oil can spread out over a considerable area due to random motion of the water but for the purposes of this study the prediction of the location of the center of mass is sufficient. Thus diffusion was neglected.

III OCEANOGRAPHIC and METEOROLOGICAL DATA

i. Currents

method does not ensure mass conservation

A grid of seasonal residual surface-layer currents, using historical data, was constructed on a one-quarter degree square. The data examined included: measurements from moored current meters as reported in the literature (e.g. Anon, 1981; Butman et al., 1982; Smith and Petrie, 1982; Smith, 1983b; Flagg et al., 1982); drift bottle and drift card releases (e.g., Bigelow, 1927; Bumpus, 1960; Bumpus and Lauzier, 1965; Bumpus, 1973; Bedford Institute of Oceanography drifter data base); satellite tracked drifters (e.g., Trites et al., 1981a; Butman et al., 1982; Flagg et al., 1982); and calculated and theoretically deduced circulation patterns (e.g., Vermersch and Beardsley, 1979; Loder, 1980; Greenberg, 1983). From this range of sources and employing visual interpolation and extrapolation, residual current speed and direction values were assigned to each grid box for summer and winter (Fig. 2a, b). Although these current grid maps may include a climatic wind component, they are assumed to be small in comparison to the total of the other components (e.g., tidal rectification, longshore pressure gradients, density gradients). At each time step the value for residual current was obtained by spatial interpolation (Cressman, 1959) extending over a radius equal to the grid spacing (28 km).

ii. Winds

Lacking any regular and long time-series wind measurements at sites on Georges and Browns Banks, data from Sable Island was chosen. Previous studies have shown that this offshore site is representative of the outer continental shelf conditions over a relatively broad area (Trites and Banks, 1958; Petrie and Smith, 1977; Petrie and Lively, 1979). From the hourly observations 24-hour vector averaged winds were computed. Data for the 23-year period, 1956-78 were used.

IV RESULTS

Trajectories were computed for 6 release sites located on Georges Bank, Browns Bank, and in the eastern Gulf of Maine. Two start times were chosen for each site, one commencing on 1 June (summer) and the other on 1 December (winter) for each year in the 23-year period, 1956-78. In Figure 3a the 20-day summer trajectories are shown for the site B start point. This figure shows that the clockwise gyre on Georges Bank exerts an important influence on the trajectories during this period. The bulk of the trajectories move initially towards the southwest, against the climatically prevailing winds from the southwest, indicating that in this area in summer the current tends to dominate over the wind in moving floating oil. A number of the trajectories are almost coincident with the gyre on Georges Bank. However, on the northwest side of the Bank and in the southern Gulf of Maine the currents and summer winds generally reinforce each other with the result that there is a relatively rapid translation towards the northeast. After 40 days (Fig. 3b) the end points of most of the trajectories are located to the north and east of the start point, and have reached the southwestern Scotian Shelf and even into the Bay of Fundy. A number have approached the Nova Scotia coastline. After 80 days (Fig. 3C), only one trajectory end-point remains on Georges Bank. Another is located offshore southwest of the start point. All of the other end-points are located on the Scotian Shelf, in the Bay of Fundy, and along the northeastern coast of Maine. Many have reached the New Brunswick and Nova Scotia coastline around the Bay of Fundy.

When viewed over the 80-day period, most of the trajectories display a broadly similar feature; namely, a net movement to the northeast of several hundred kilometers. The year-to-year variation in wind conditions results in a relatively wide distribution of end-points. Nevertheless there is some tendency for the end-points to cluster in one or more groupings. By joining the peripheral points, an envelope can be constructed which can be interpreted as the region which is threatened at a given time following a spill at, in this instance, site B. In

Figure 4, 20-day, 40-day, and 80-day smoothed envelopes are shown for the summer trajectory plots illustrated in Figures 3a, b, c.

A smoothed envelope containing the 20-day end-points for a winter start point at site B is shown in Figure 5. Compared to the 20-day summer envelope (Fig. 4) it is smaller with a net offshore displacement. The shift in prevailing wind direction (blowing from the southwest in summer and from the northwest in winter) combined with a weakened Georges Bank gyre, results in a net translation southward and offshore from site B. The 40-day and 80-day envelopes have not been shown as the trajectories all reached the offshore geographic limits of the area modelled before the end of 40 days.

Summer trajectory envelopes for a site A start point are shown in Figure 6. The rapid translation to the northeast over the first 20 days arises because the current and prevailing winds are acting in nearly the same direction along the northwestern part of Georges Bank and the southern portion of the Gulf of Maine. At the end of 20 days the envelope extends from the northern part of Georges Bank to the western tip of Nova Scotia. After 40 days the envelope reaches from the eastern tip of Georges Bank to the Bay of Fundy and encompasses much of the southwestern Scotian Shelf. At the end of 80 days end-points are contained within four cluster areas. Trajectories extend to the inner end of the Bay of Fundy, and others have reached the eastern limits of the modelled portion of the Scotian Shelf. The two small clusters (one north of Georges Bank and one south of it) appear to have resulted from the "splitting" effect of the circulation patterns, particularly in the Georges Bank area.

The winter envelope pattern for site A shows a net offshore movement with all trajectories reaching the offshore limits of the modelled area in less than the 80 day period (Fig. 7). Although the Georges Bank gyre plays an important role in determining the 20-day envelope, the prevailing northwest winds produces the net offshore translation to the southeast over the longer time period.

Summer and winter envelopes are shown respectively in Figures 8 and 9 for a start point in the eastern Gulf of Maine (site E). As might be expected the summer and winter patterns are markedly different. In summer the 20 and 40-day envelopes include the Bay of Fundy and the northeastern part of the Gulf of Maine. All trajectories reach the shoreline before 80 days have elapsed. In winter the 20 and 40-day envelopes extend eastward and southeastward from the release site, with the southern tip of Nova Scotia contacted in less than 20 days. All trajectories either contact the shoreline or extend beyond the eastern and southeastern limits of the modelled area prior to 80 days.

The summer and winter envelopes for site F (Browns Bank) are shown in Figures 10 and 11. The summer trajectory end-points tend to cluster in two areas. The lack of shoreline contact near the southern tip of Nova Scotia appears to have been brought about by the relatively strong currents in the area. In winter there is no apparent envelope "splitting" in the Cape Sable area, and the envelopes do not penetrate into the Bay of Fundy. All trajectories either contact the shoreline (in the Yarmouth-Cape Sable area) or extend beyond the limits of the modelled area before 80 days have elapsed.

Trajectories for sites C and D start points (compiled but not illustrated) are consistent with those from the other sites, confirming the general net displacement to the northeast in summer and to the southeast in winter.

V. DISCUSSION

This model differs from that used successfully in the Kurdistan oil spill off the Nova Scotia coast (Trites, et al., 1981b). In the interests of securing a very long time series, wind drift was calculated from direct wind observations at a single site rather than from atmospheric pressure maps. However, the site used (Sable Island) is believed to be very representative of continental shelf winds. With 24-hr averaging, it should be representative over large distances. In the Kurdistan model, it was felt important to attempt to correct the historical residual surface current data for a direct wind induced component. In the present work this was not done, but the relative importance of such a correction would be smaller as residual currents in the area are generally stronger than on the northeastern Scotian Shelf.

There is clearly not a one-to-one correspondence between the envelopes constructed and the areas threatened with oil pollution should a spill occur at any one of the designated sites. The spread in the trajectory end-points is generated by the year-to-year variation in wind speed and direction only. The currents employed in the model are assumed to be temporally constant throughout a given season and thus make no contribution to spreading the trajectory end-points. Although the data base is too fragmentary to permit construction of a current pattern for each year, important within-year and year-to-year variations are known to occur, owing to a number of factors (e.g., offshore forcing associated with the Gulf Stream system (Trites et al., 1981a; Smith and Petrie, 1982), fresh water discharge (Bumpus, 1960)). Thus if the trajectory modelling included the year-to-year variation in current patterns, the spread in the trajectory end-points would be even greater. Another process, neglected in this study is turbulent diffusion. It too would, if included, act in the direction of further increasing the spread in trajectory end-points.

The separation of end-points into two or more clusters appears to be enhanced by the spatially varying current pattern, but the magnitude of the scatter will be quite dependent on the timing of a particular wind event in relation to the geographic location of the trajectory end-point at that time. For example, a wind blowing from the north or northwest for a day or two when a path along the northern part of Georges Bank is being traced out, easily might result in the subsequent trajectory turning southward and around the Georges Bank gyre, or offshore. An oppositely directed wind event likewise could easily result in a trajectory leading into the Bay of Fundy. It seems highly probable that a longer wind data set alone, would also give rise to appreciably larger envelopes. Thus the envelopes depicted in this study should be considered appreciably smaller than the area that is in fact threatened should an oil spill occur at any one of the given sites.

VI. SUMMARY AND CONCLUSIONS

Although the oceanographic and meteorological data bases are not as complete as desired, and the physical behaviour of spilled oil remains poorly understood, a semi-quantitative delineation can be made of the areas threatened from offshore oil spills on the Continental Shelf in the Georges Bank, Browns Bank, and eastern Gulf of Maine area.

Envelopes are constructed which are inferred to represent the areas subsequently threatened over 20, 40, and 80 day periods following a hypothetical oil spill at a number of offshore sites. However, if the year-to-year variability in the surface layer currents were to be included in the model, the spread in the trajectory end-points, and hence the size of the area threatened, would undoubtedly be much larger than those depicted in this study.

The results of this study show that there is a marked seasonal change in the pattern of movement away from all hypothetical spill sites on Georges Bank, Browns Bank, and the eastern Gulf of Maine. In summer the net movement, for periods longer than 20 days is generally to the northeast, whereas in winter, the net movement is generally offshore towards the southeast. The fact that trajectories in summer frequently intersect the coastline of southwest Nova Scotia as well as that of the Bay of Fundy indicate that this area is threatened with oil pollution should a spill occur anywhere in the area from Browns Bank westward. In winter, the threat of coastline pollution from spills on Browns Bank and Georges Bank is much reduced compared to a summer spill.

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Figure Captions

Figure 1 — Map showing general bathymetry of the area modelled, together with sites at which simulated oil-drift trajectories were computed.

Figure 2a — Grid displaying summer surface layer mean currents. Within each grid-box the direction (°T) in which the current is flowing (upper number) and the speed (cm/sec, lower number) are shown.

Figure 2b — Grid displaying winter surface layer mean currents. Within each grid-box the direction (°T) in which the current is flowing (upper number) and the speed (cm/sec, lower number) are shown.

Figure 3a — 20-day summer trajectories computed for site B start point (eastern Georges Bank). One trajectory is computed for each year in the 1956-78 period.

Figure 3b — 40-day summer trajectories computed for site B start point (eastern Georges Bank). One trajectory is computed for each year in the 1956-78 period.

Figure 3c — 80-day summer trajectories computed for site B start point (eastern Georges Bank). One trajectory is computed for each year in the 1956-78 period.

Figure 4 Smoothed envelopes encompassing the 20-day 40-day, and 80-day summer trajectory end-points, for site B start point (eastern Georges Bank).

Figure 5 Smoothed envelope encompassing the 20-day winter trajectory end-points, for site B start point (eastern Georges Bank).

Figure 6 Smoothed envelopes encompassing the 20-day, 40-day, and 80-day summer trajectory end-points for site A start point (southwestern Georges Bank). More than one envelope is depicted for the 80-day end-points owing to the wide scatter, combined with evidence of clustering.

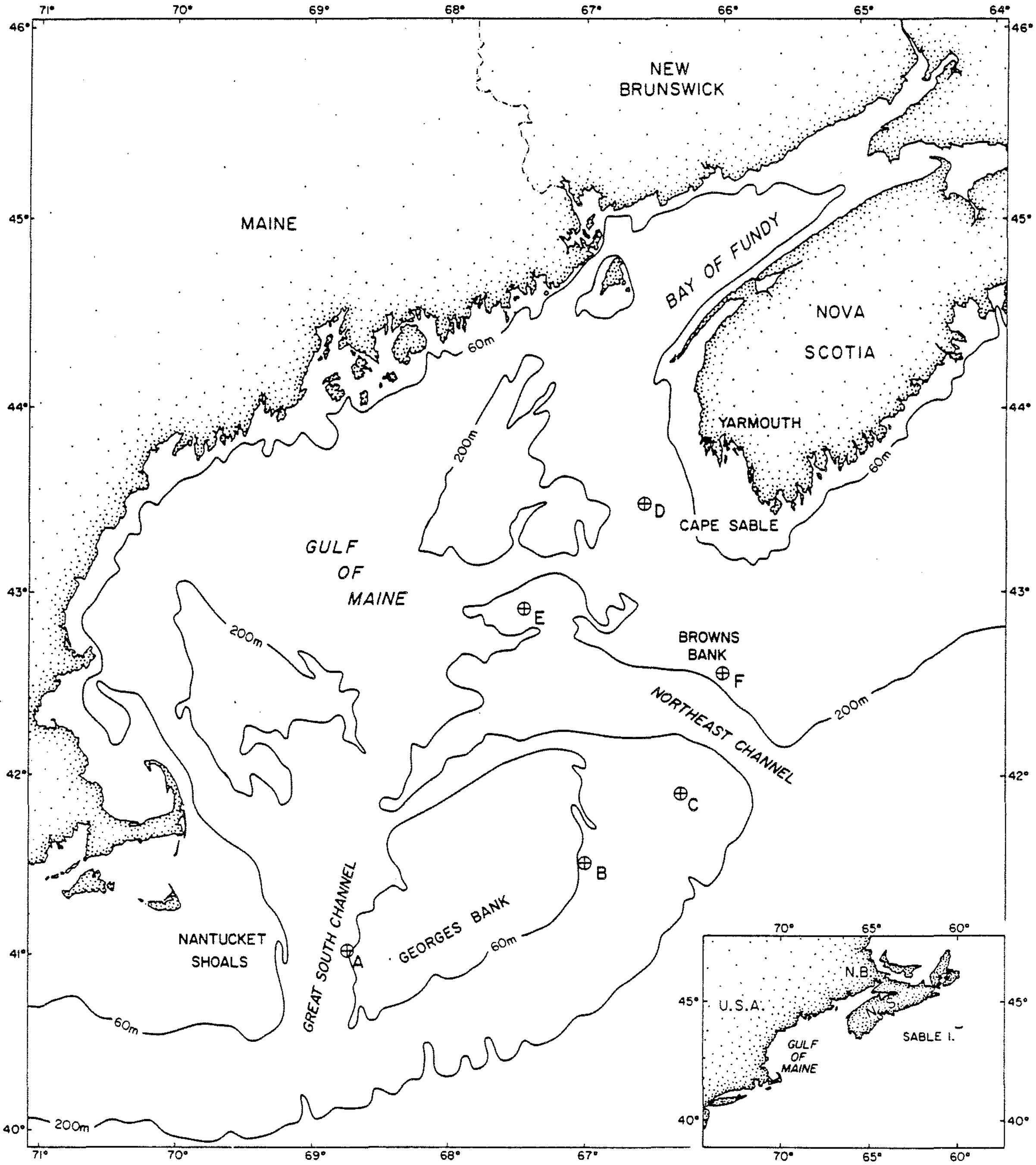
Figure 7 Smoothed envelopes encompassing the 20-day and 40-day winter trajectory end-points for site A start point (southwestern Georges Bank).

Figure 8 Smoothed envelopes encompassing the 20-day and 40-day summer trajectory end-points for site E start point (eastern Gulf of Maine).

Figure 9 Smoothed envelopes encompassing the 20-day and 40-day winter trajectory end-points for site E start point (eastern Gulf of Maine). The bulk of the trajectory end-points reached the offshore limits of the area modelled before 40 days elapsed.

Figure 10 Smoothed envelopes encompassing the 20-day, 40-day and 80-day summer trajectory end-points for site F start point (Browns Bank). Clustering in the Bay of Fundy and on the Scotian Shelf gives rise to two envelopes being shown for each time period. On the Scotian Shelf several trajectory end-points reached the eastern limit of the area modelled within the 20-day period. The numbers reaching this eastern boundary continued to increase with time.

Figure 11 Smoothed envelopes encompassing the 20-day and 40-day winter trajectory end-points for site F start point (Browns Bank). The bulk of the trajectory end-points reached the offshore limits of the area modelled before 40 days elapsed.



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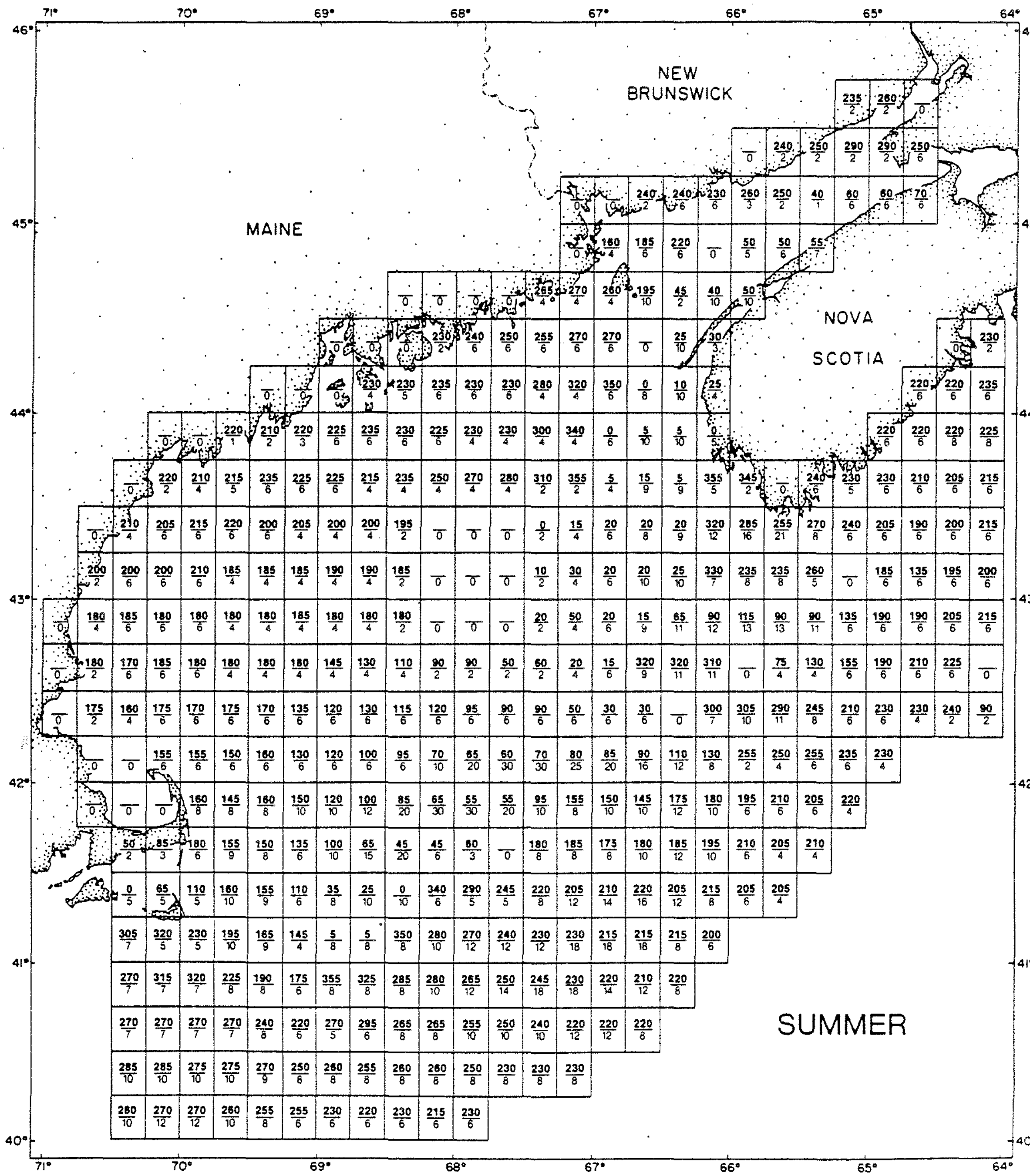

Figure 2a Grid displaying summer surface layer mean currents. Within each grid-box the direction (°T) in which the current is flowing (upper number) and the speed (cm/sec, lower number) are shown.

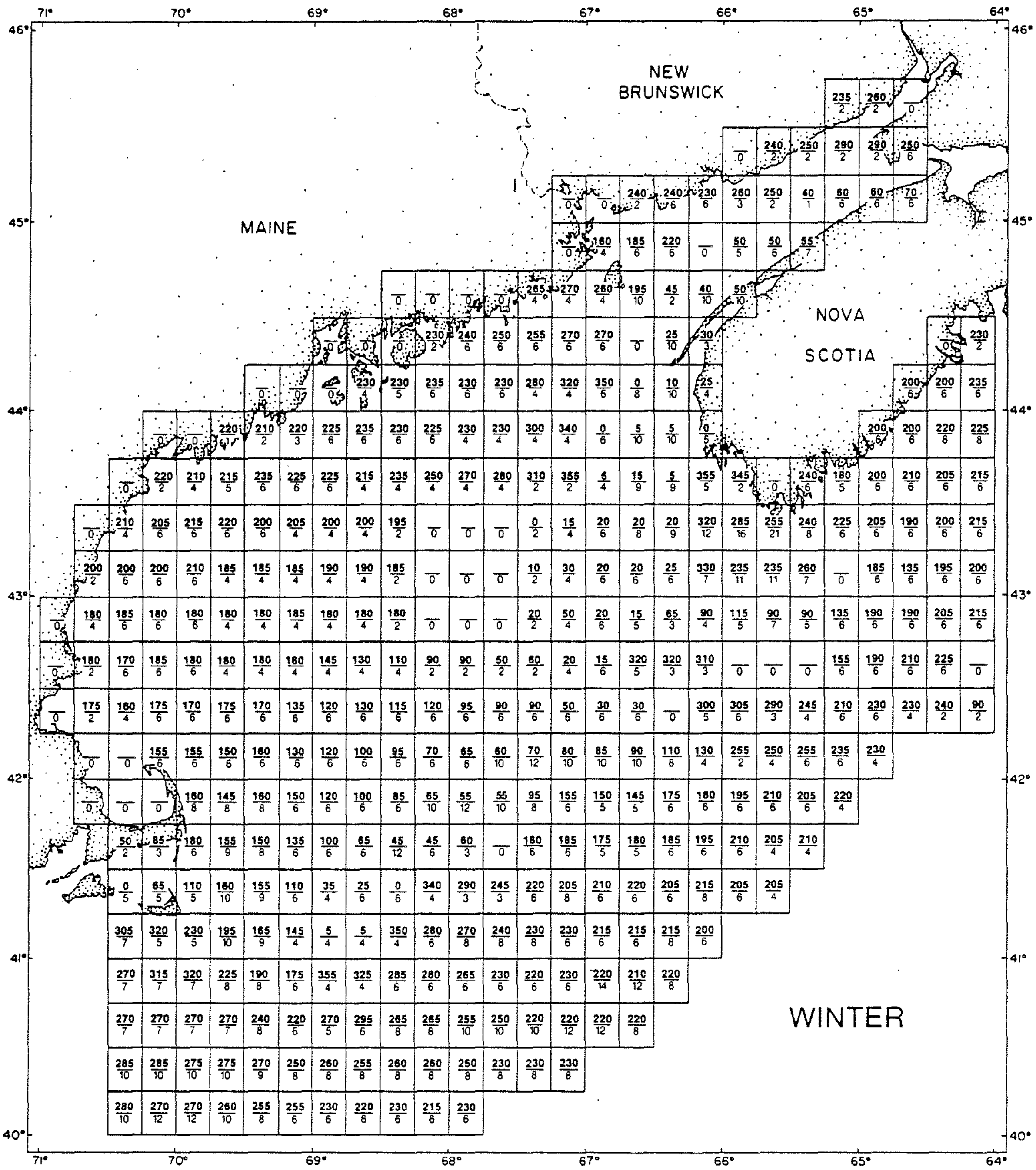

Figure 2b Grid displaying winter surface layer mean currents. Within each grid-box the direction (°T) in which the current is flowing (upper number) and the speed (cm/sec, lower number) are shown.

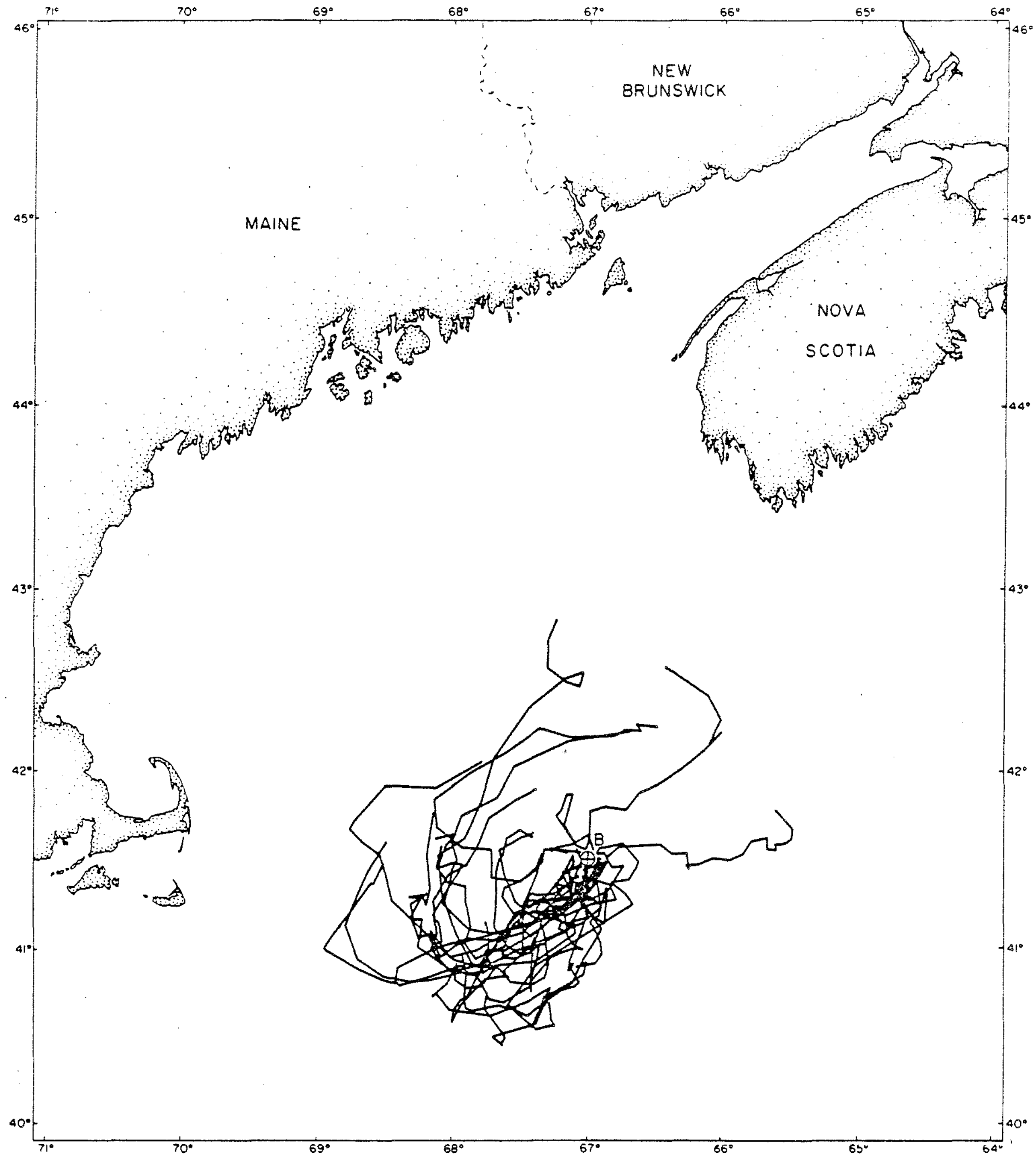

Figure 3a 20-day summer trajectories computed for site B start point (eastern Georges Bank). One trajectory is computed for each year in the 1956-78 period.

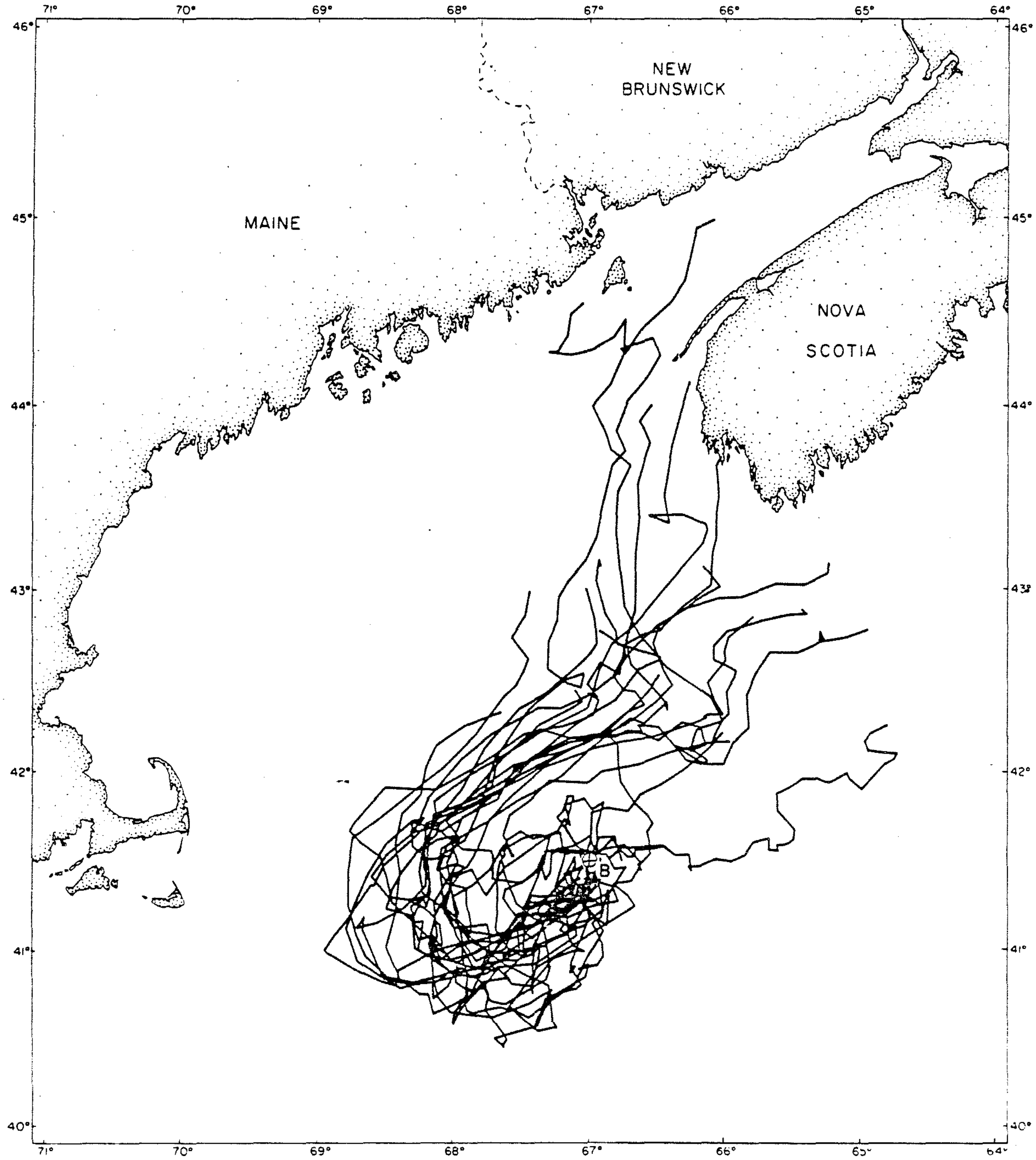

Figure 3b 40-day summer trajectories computed for site B start point (eastern Georges Bank). One trajectory is computed for each year in the 1956-78 period.

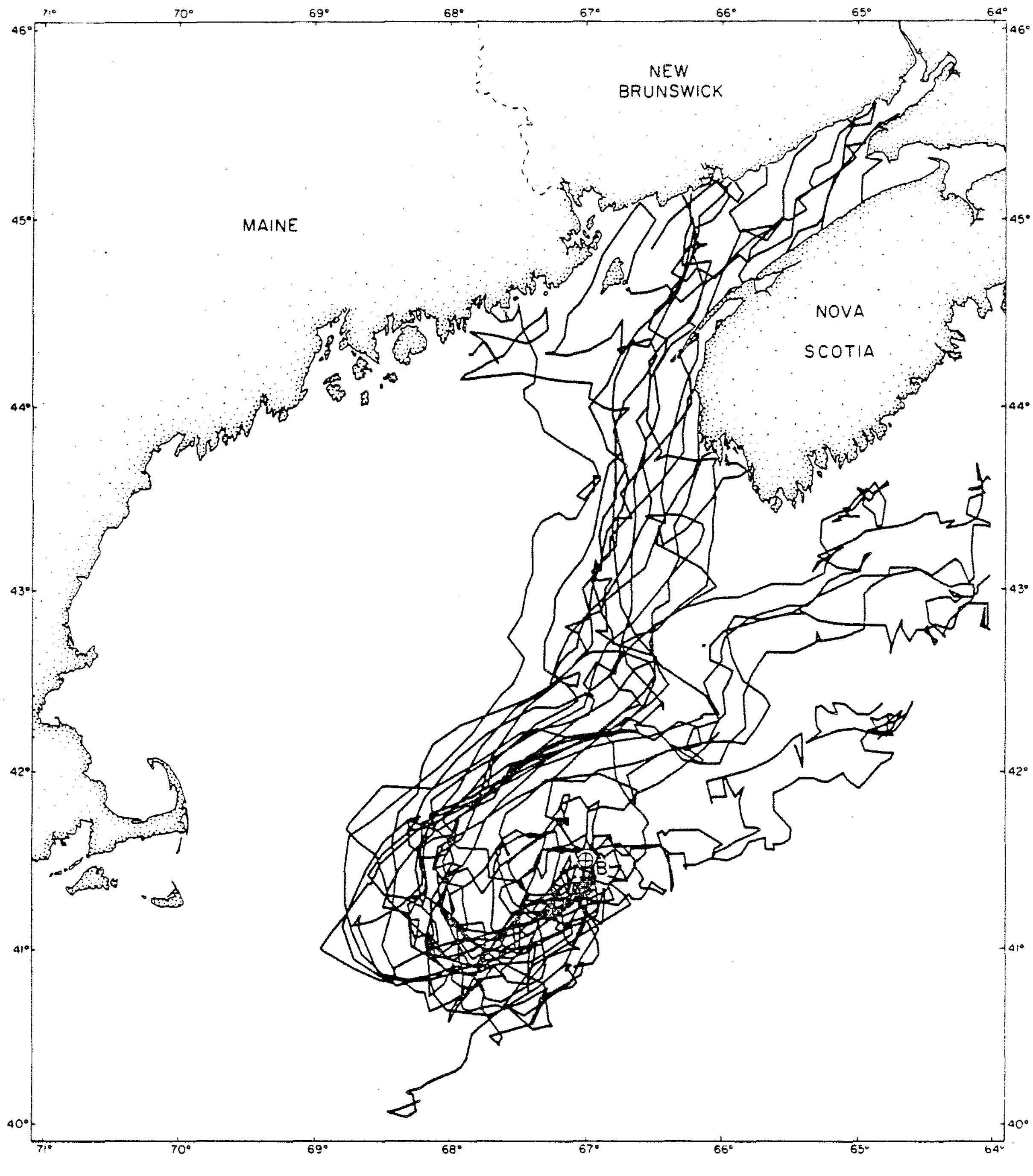

Figure 3c 80-day summer trajectories computed for site B start point (eastern Georges Bank). One trajectory is computed for each year in the 1956-78 period.

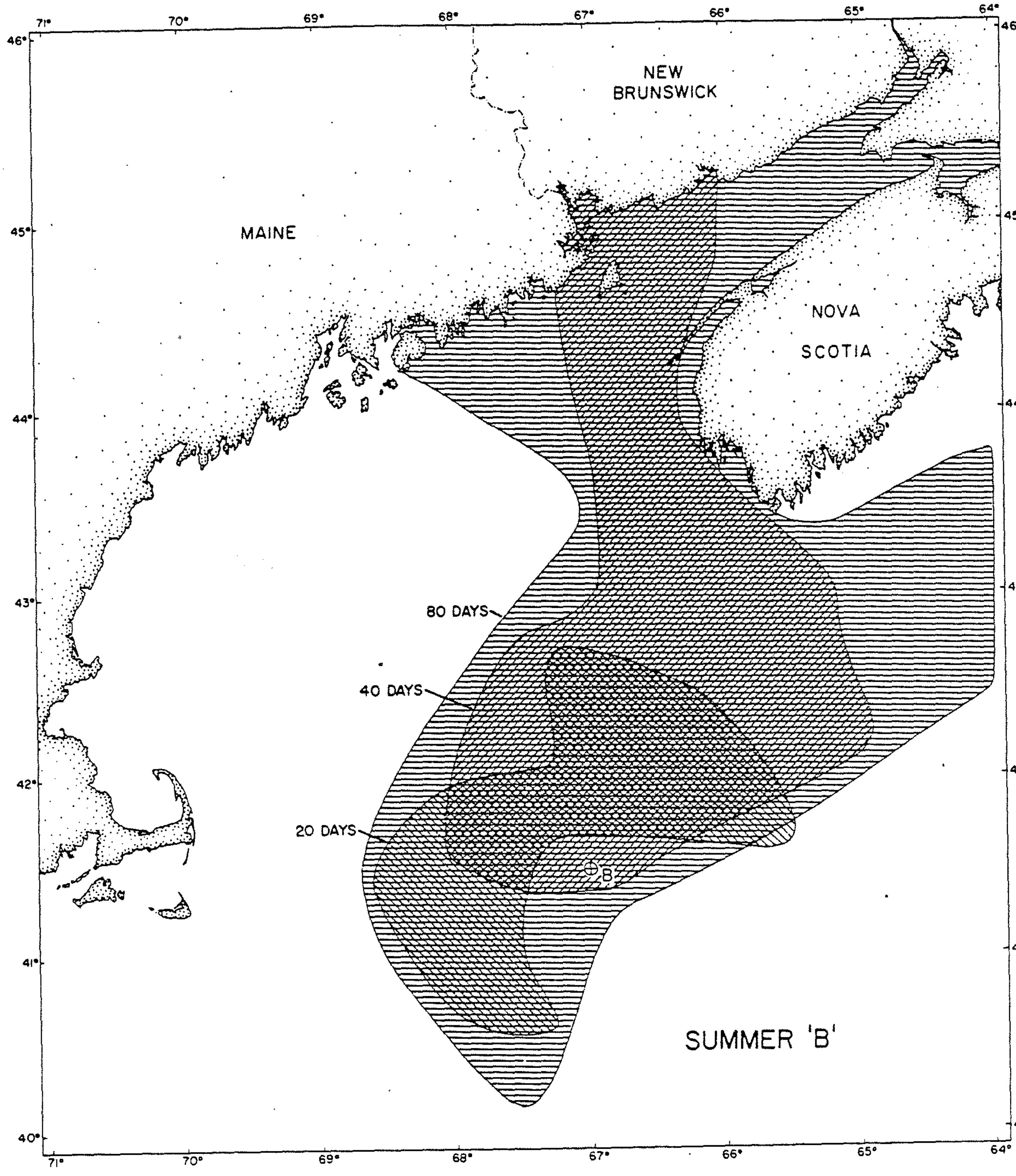

Figure 4 Smoothed envelopes encompassing the 20-day, 40-day, and 80-day summer trajectory end-points, for site B start point (eastern Georges Bank).

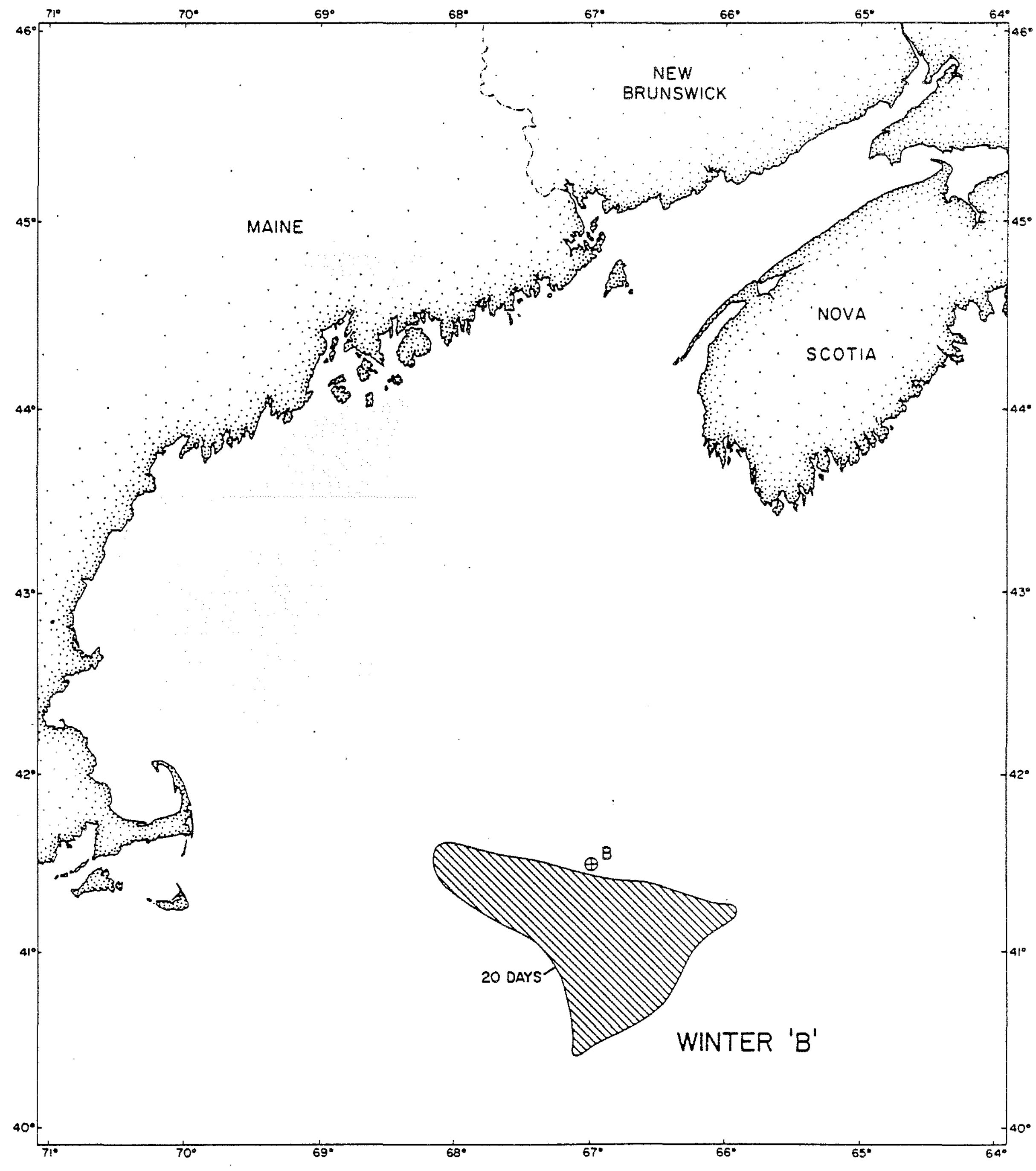

Figure 5 Smoothed envelope encompassing the 20-day, winter trajectory end-points, for site B start point (eastern Georges Bank).

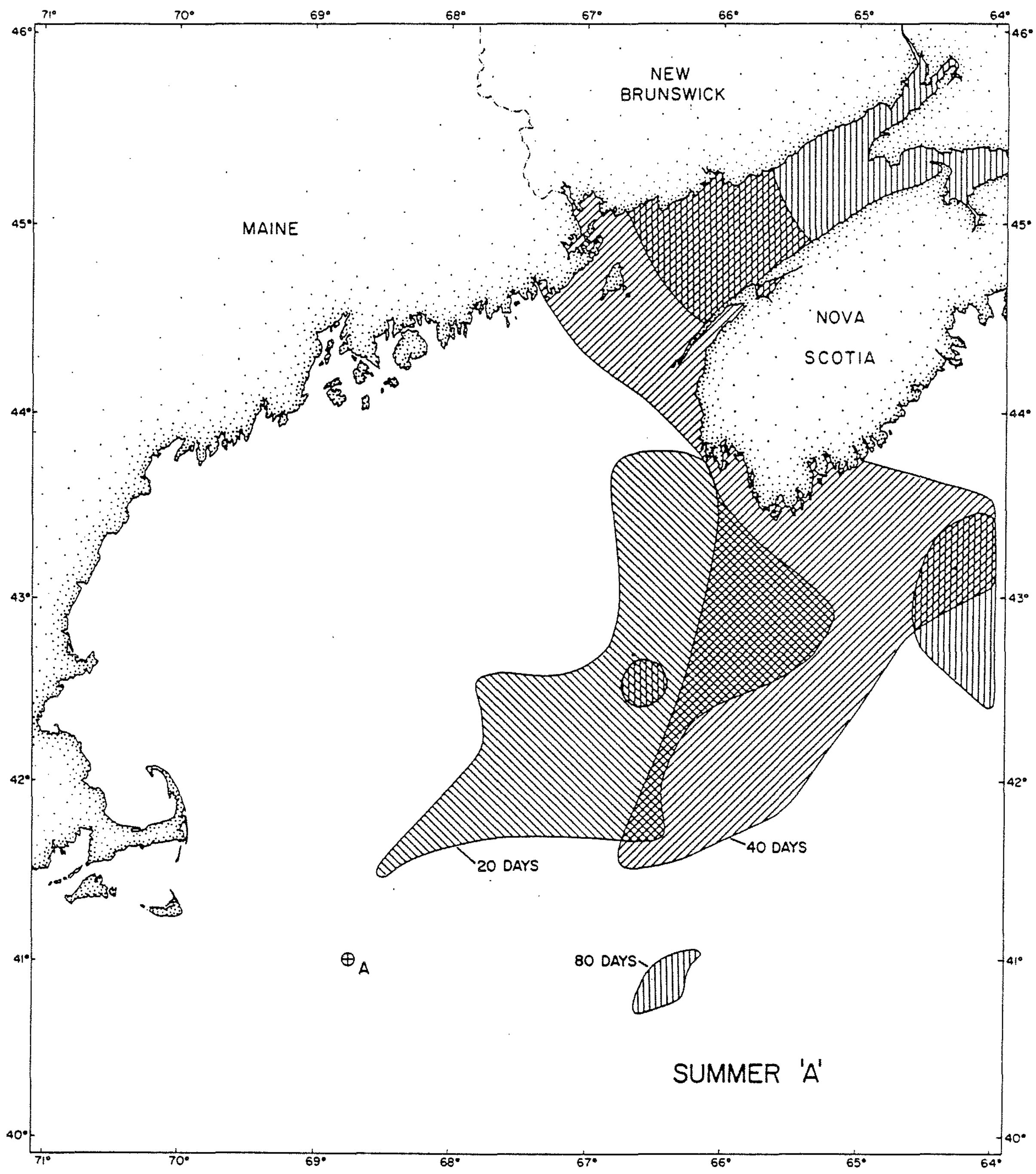

Figure 6 Smoothed envelopes encompassing the 20-day, 40-day, and 80-day summer trajectory end-points for site A start point (southwestern Georges Bank). More than one envelope is depicted for the 80-day end-points owing to the wide scatter, combined with evidence of clustering.

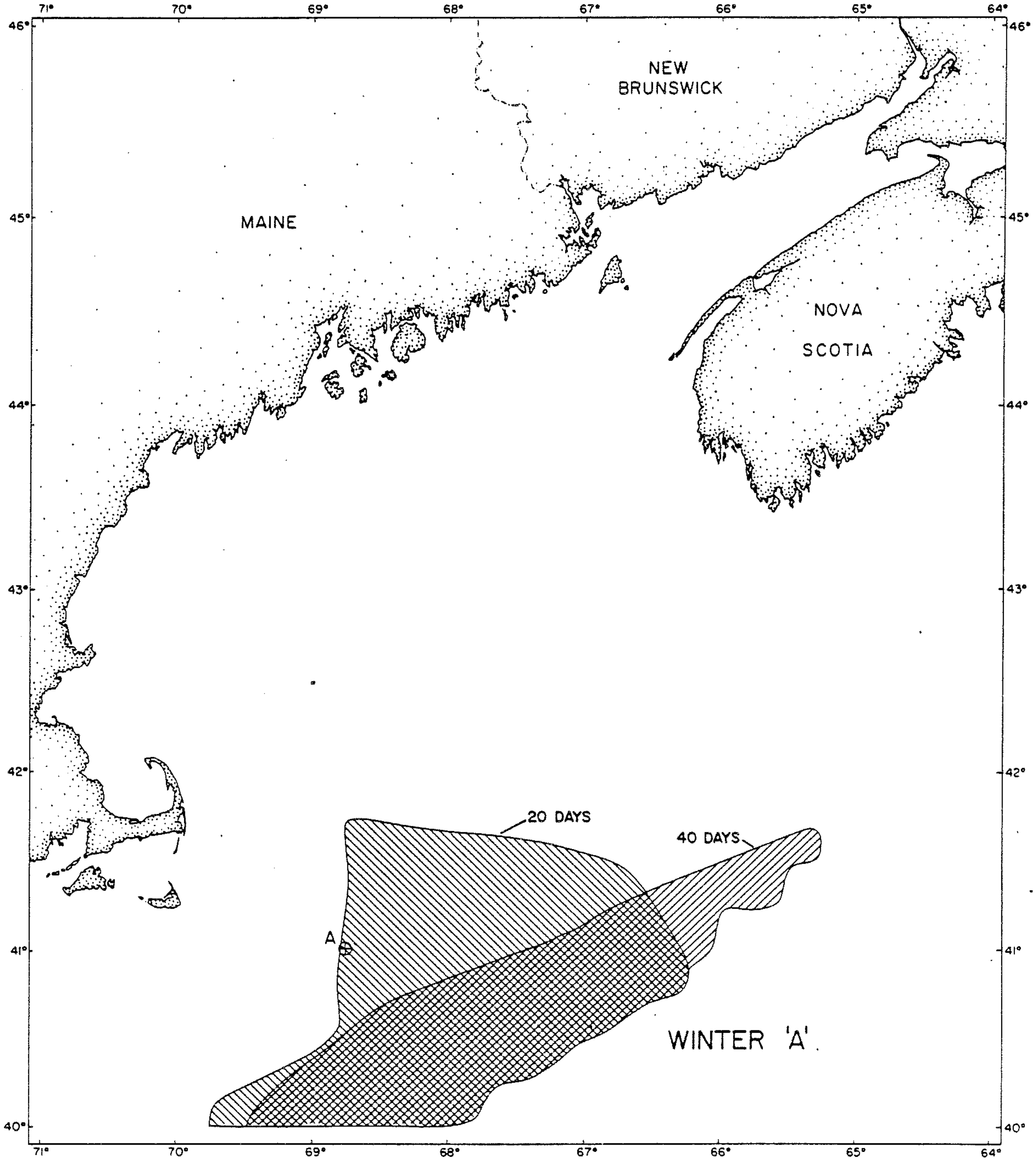

Figure 7 Smoothed envelopes encompassing the 20-day and 40-day winter trajectory end-points for site A start point (southwestern Georges Bank).

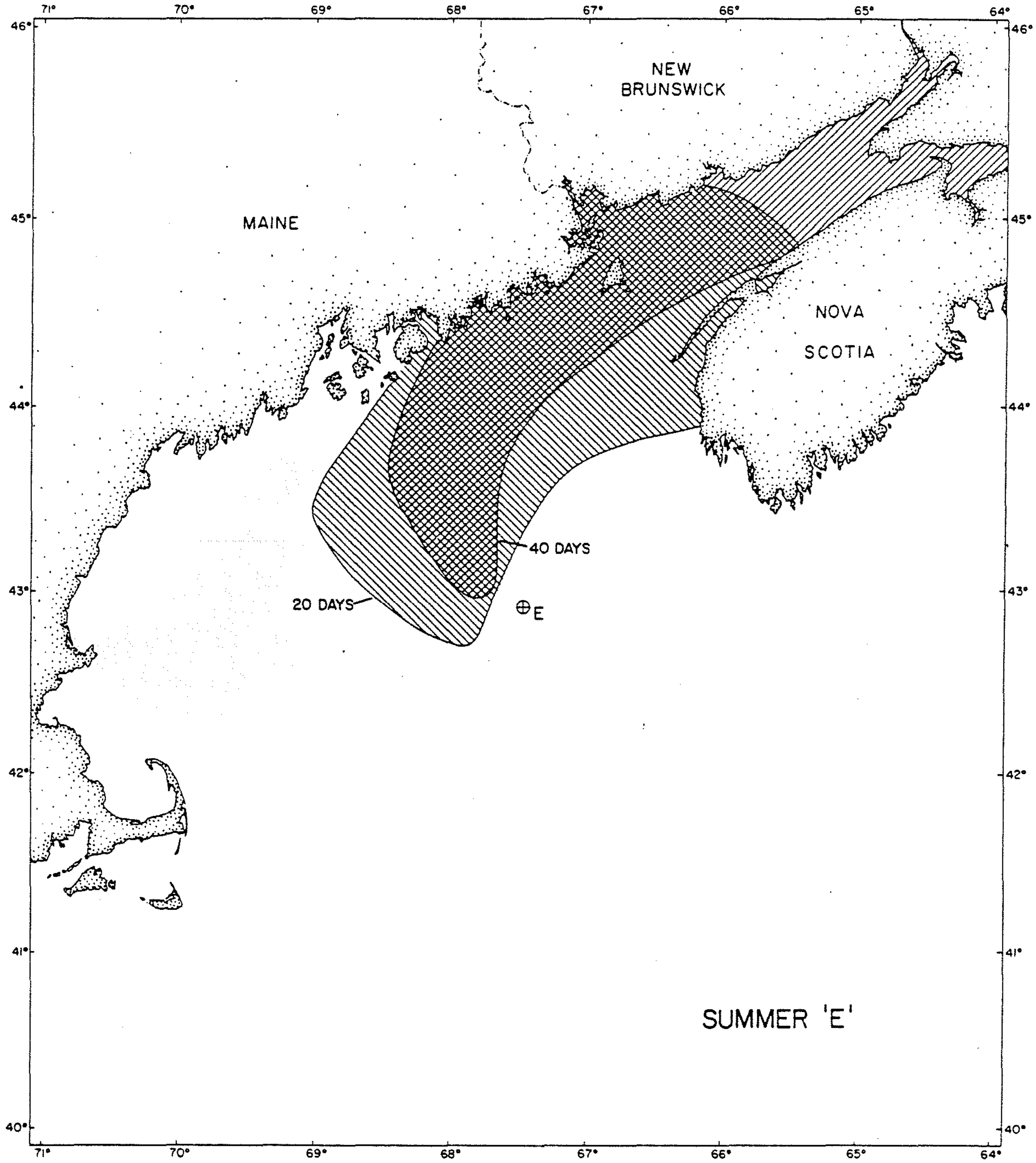

Figure 8 Smoothed envelopes encompassing the 20-day and 40-day summer trajectory end-points for site E start point (eastern Gulf of Maine).

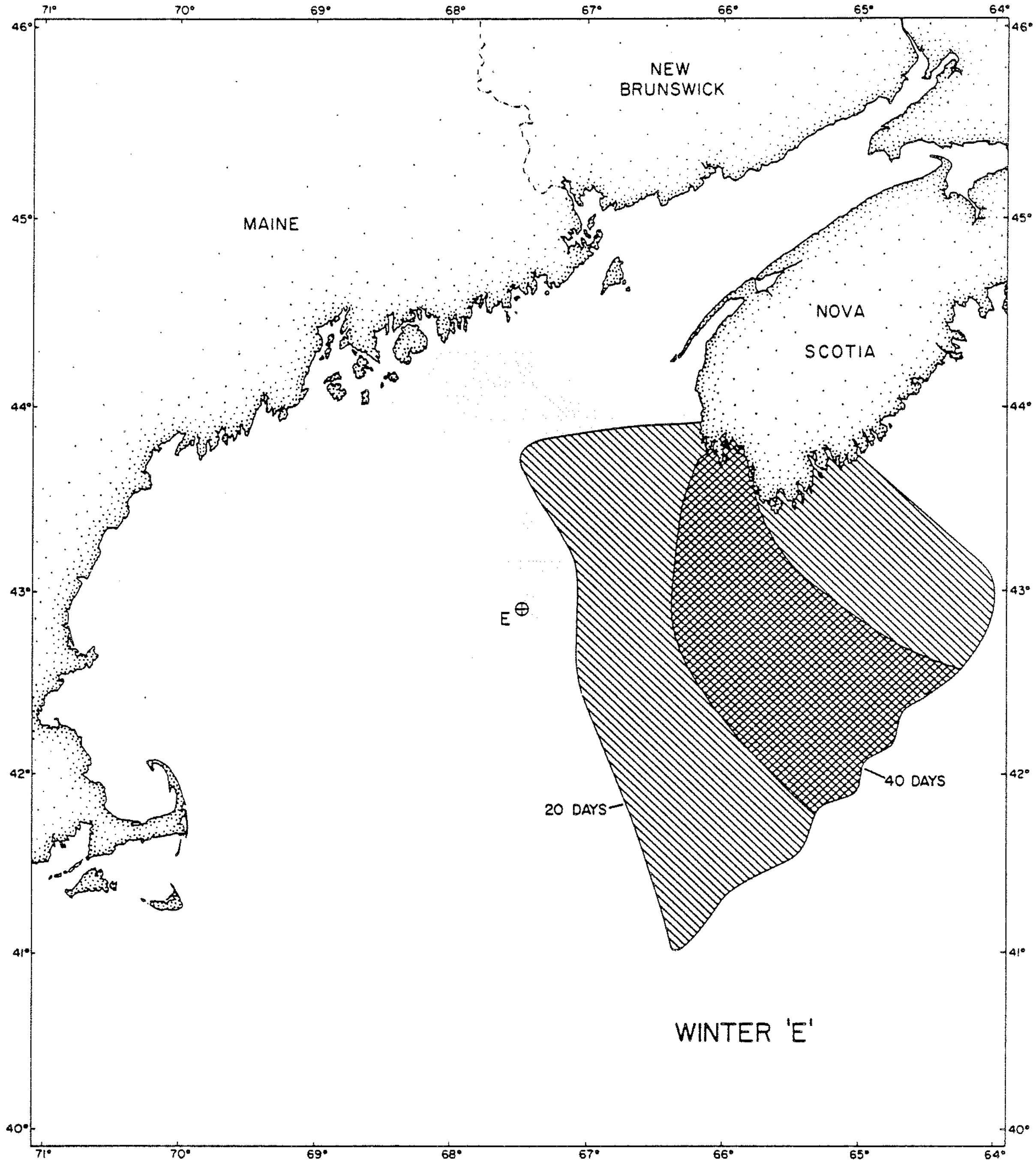

Figure 9 Smoothed envelopes encompassing the 20-day and 40-day winter trajectory end-points for site E start point (eastern Gulf of Maine). The bulk of the trajectory end-points reached the offshore limits of the area modelled before 40 days elapsed.

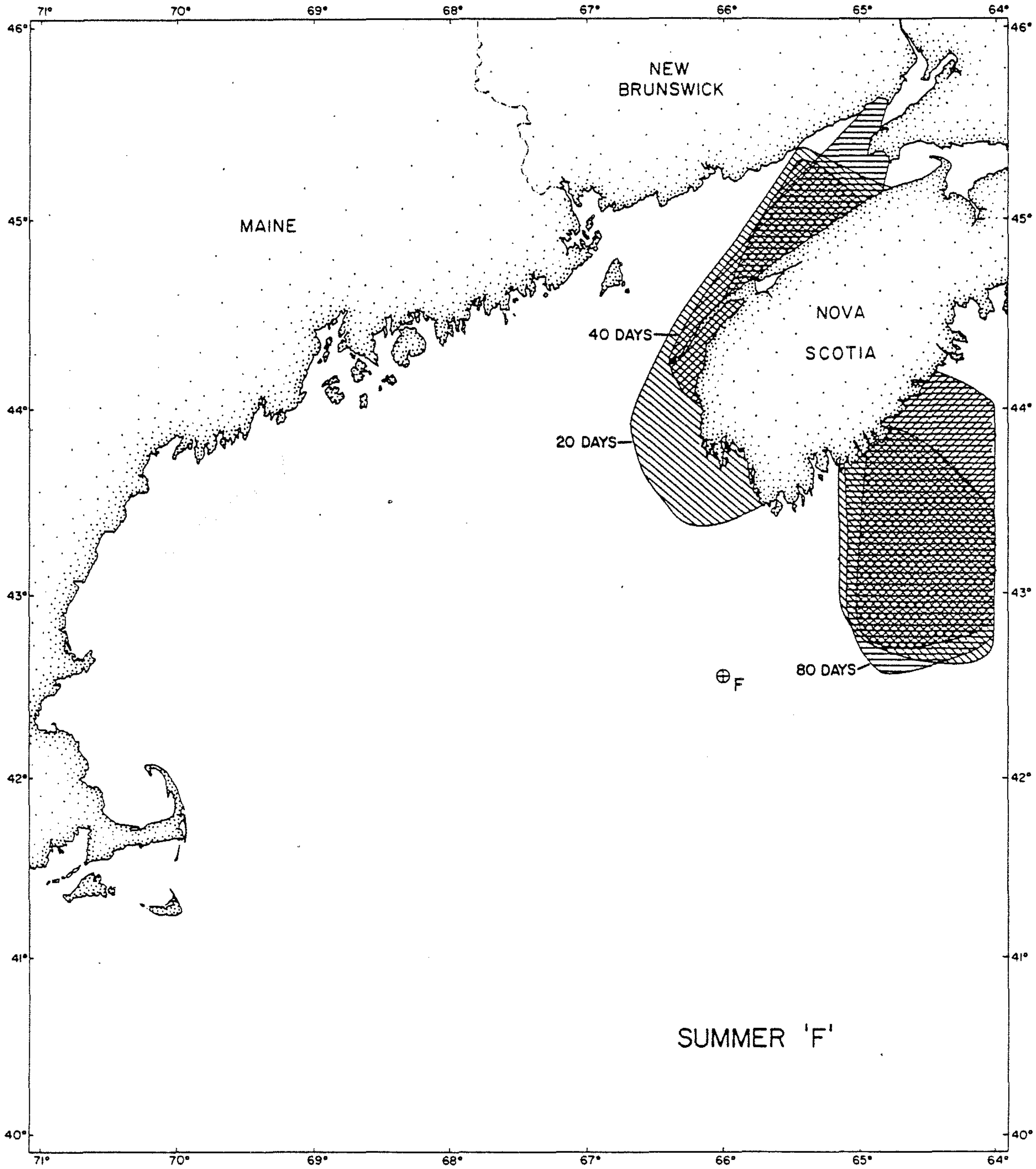

Figure 10 Smoothed envelopes encompassing the 20-day, 40-day and 80-day summer trajectory end-points for site F start point (Browns Bank). Clustering in the Bay of Fundy and on the Scotian Shelf gives rise to two envelopes being shown for each time period. On the Scotian Shelf several trajectory end-points reached the eastern limit of the area modelled within the 20-day period. The numbers reaching this eastern boundary continued to increase with time.

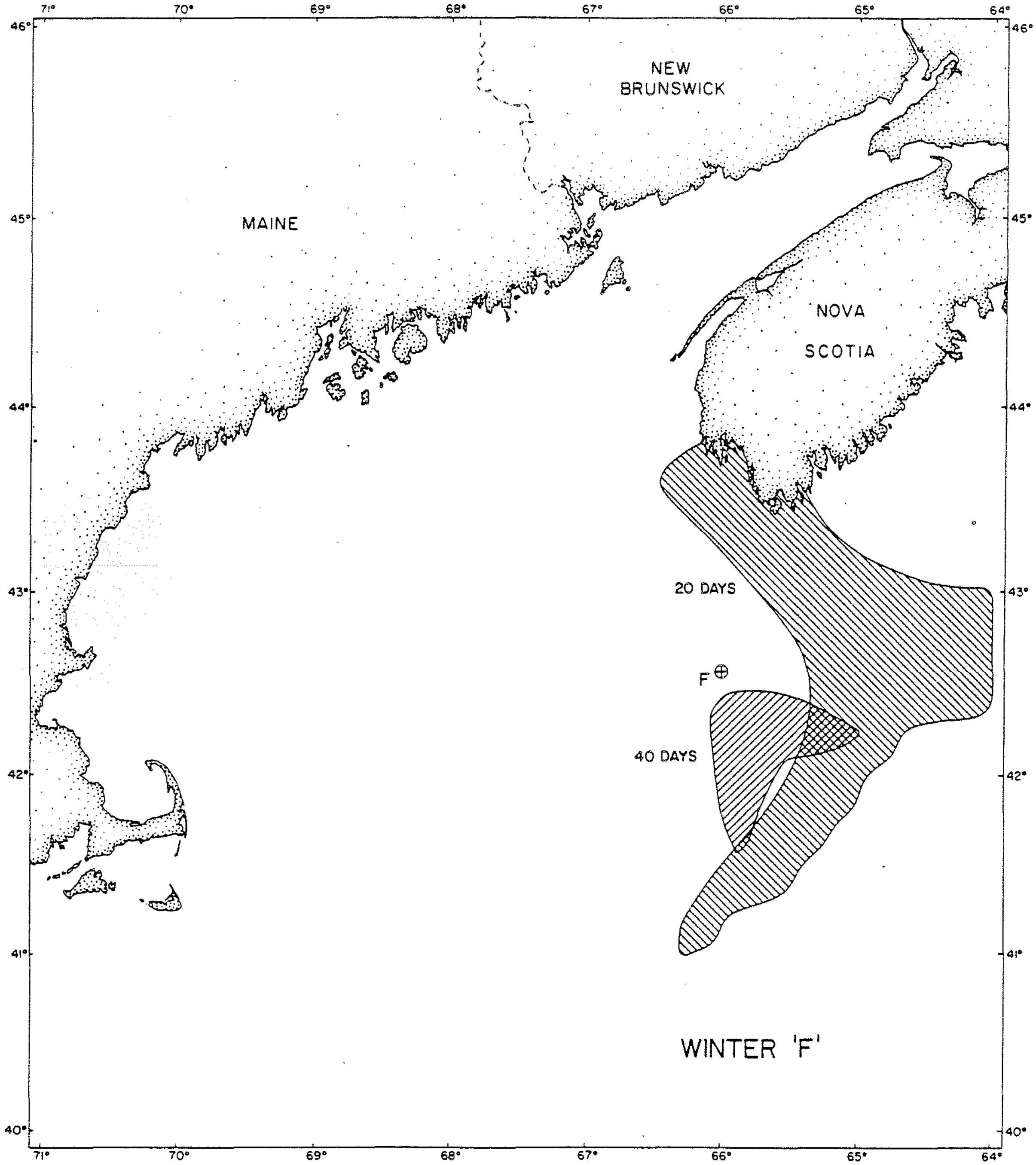

Figure 11 Smoothed envelopes encompassing the 20-day and 40-day winter trajectory end-points for site F start point (Browns Bank). The bulk of the trajectory end-points reached the offshore limits of the area modelled before 40 days elapsed.