# FOREWORD

Marine contamination by petroleum, whether by natural seepage or by spills from ships at sea, by accidents in harbour or at offshore installations or by atmospheric or terrigenous input is by no means a new or rare phenomenon. In recent years however, the problems have been highlighted not only by the increased utilisation and marine transport of oil but also by a number of spectacular accidents which have raised questions about possible effects on the ecosystem. A number of detailed studies have been carried out in an attempt to answer these questions. The demands for such knowledge have been further increased by the various questions raised as a result of expansion of offshore exploration and exploitation for oil, particularly in environments hostile to these operations, in regions as far apart as the northern North Sea and the coast of Alaska.

Consequently, diverse aspects of the problem are being studied in several parts of the world by chemists and biologists who are often asking the same questions but using different approaches and sometimes producing conflicting views. Against this background, it seemed timely therefore to bring together a group of scientists from university, industry and government, actively engaged in such work, to examine and discuss common problems relevant to petroleum hydrocarbon contamination of the marine ecosystem and so a Workshop was sponsored by the International Council for the Exploration of the Sea, and held in Scotland at Aberdeen in September 1975.

The Workshop considered methodology, occurrence and fate in the environment, and effects on the ecosystem of petroleum hydrocarbons in the sea. Most of the papers presented and updated where necessary, are brought together in the present volume together with an edited version of the recorded discussion that followed each session. Of necessity, the reportage of the discussion is very brief although the proportion of time available for discussion compared favourably with that set aside for formal presentation of the papers. In preparing the discussion reports, the editors were assisted in particular by Dr R. Hardy, Dr R. Johnston, Mr P. R. Mackie and Dr I. C. White, and by comments from several contributors.

No attempt was made to produce specific recommendations but a study of the papers in this volume does give a clear indication of several lines of research which must be followed up before an adequate understanding can be reached of the effects of petroleum in the sea and it is evident that widespread monitoring operations will be fully effective only when the basis of our knowledge has been thus extended.

A list of participants to the workshop may be found in Appendix I.

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Rapp. P.-v. Réun. Cons. int. Explor. Mer, 171: 55–60. 1977.

# THE GEOGRAPHICAL DISTRIBUTION OF TAR IN THE NORTH ATLANTIC

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The results obtained from 1971 to 1974 in a continuing study of the distribution of tar on the surface of the North Atlantic are presented. In the waters to the north and west of the Gulf Stream/North Atlantic Current system tar pollution was virtually nonexistent. On the other hand, pollution was extensive elsewhere with the highest concentrations in the Sargasso Sea. The observed distribution is considered in terms of the inputs and the circulation of North Atlantic surface waters.

## INTRODUCTION

In February 1970, the tanker, "Arrow", grounded in Chedabucto Bay, Nova Scotia, spilling some 16 000 tonnes of Bunker C fuel oil. Consequently, the Bedford Institute of Oceanography immediately undertook a broad variety of studies associated with the effects of the oil on the marine environment (Anon, 1970). Included in these studies was an estimation of the amount of oil that was dissolved or dispersed in the waters of the Bay and its effect on background levels in adjacent waters (Levy, 1971, 1972). Shortly after these investigations were begun, vivid descriptions of the 'shocking' pollution of the North Atlantic by floating petroleum residues and other wastes from human civilization were published by Heyerdahl (1971). Since the few semi-quantitative measurements of tar concentrations reported in the literature (Horn, Teal and Backus, 1970) were not sufficiently comprehensive to permit an assessment of the tar pollution of the North Atlantic, it was a natural extension of our oil pollution programme to include this problem. During the period 1971 to 1974 an extensive sampling programme, which covered the North Atlantic from South America to the limit of marine navigation (about 78°N) in the Arctic and from the east coast of Canada to Europe and into the Mediterranean Sea, was carried out (Fig. 39). This paper is focused on the geographical distribution of floating petroleum residues in the North Atlantic and its dependence on inputs and the circulation of surface waters.

## METHODS

Samples of floating petroleum residues were collected by towing a modified neuston net for approximately one nautical mile at about 5–7 knots (Levy and Walton, 1971, 1973). The samples were immediately frozen and subsequently analyzed by a quantitative extraction/gravimetric procedure which has been described in detail elsewhere (Levy, 1973; Levy and Walton, 1976).

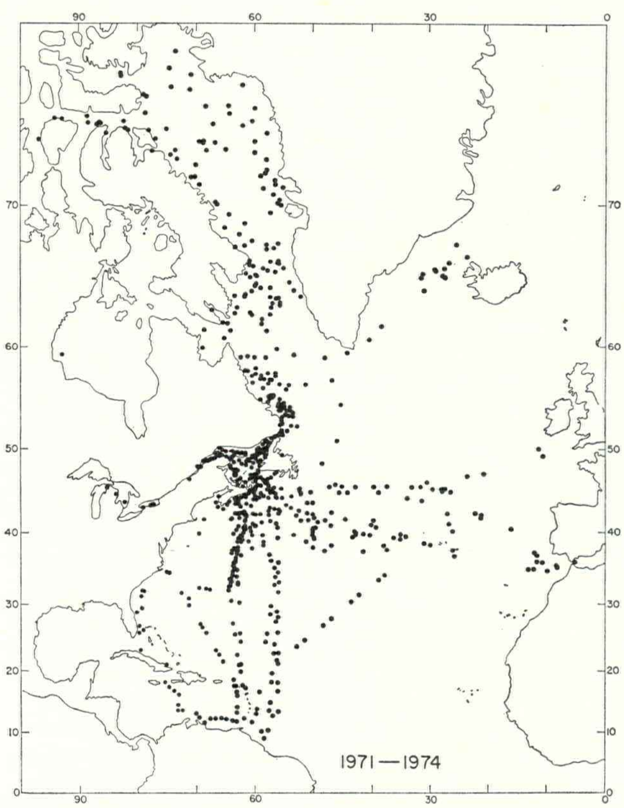


Figure 39. Locations from which samples were collected 1971–1974 inclusive.

RESULTS AND DISCUSSION

In an earlier publication (Levy and Walton, 1976), it was shown that tar concentrations in the North Atlantic* belonged to two distinct populations separated geographically. As shown in Figures 40—43, tar was essentially absent from the surface of the North Atlantic north of about 45°N latitude, whereas it was virtually ubiquitous in the more southern regions. Tar concentrations in the southern waters were previously shown to be lognormally distributed with an overall geometric mean for the 4-year period ranging between 0·13 and 0·20 $mg/m^2$ with the most likely value being 0·16 $mg/m^2$ (Levy and Walton, 1976).

Contour maps illustrating the geographical distribution of the tar found on the surface of the North Atlantic during each of the years 1971 to 1974 are shown in Figures 44—47. It is strikingly apparent from Figures 40—43 and 44—47 that tar was encountered only very rarely in waters north of about 45°N latitude. This is undoubtedly a reflection of the fact that these areas are remote from the major population centres and most of the activities associated with the production, transportation and consumption of petroleum. Particularly in the more northern regions, the occurrence of tar was nearly always associated with the recent passage of a ship, and in most cases the tar was generally in a fresh, relatively unweathered form in contrast to the older, more weathered tar present in the southern waters.

Equally striking are the high concentrations observed each year in the western Sargasso Sea. As shown in Figures 44—47, tar concentrations tended to decrease outward from this region in a manner that was very closely related to the major surface currents in the western North Atlantic.

As illustrated in Figure 48, the dominant feature of the surface circulation in the North Atlantic is the large clockwise gyre that occupies much of the region between 15° and 45°N. The inner portion of this area, the Sargasso Sea, appears to be a "trap" not only for floating seaweed but, from the data collected during this study, for a considerable portion of the tar floating in the North Atlantic. The southern boundary of the gyre, the North Equatorial Current, flows from east to west in a region about 15°N and joins with a branch of the South Equatorial Current which originated off the west coast of Africa. In the region of the Greater Antilles, the combined waters split and one portion, the Antilles Current, flows to the seaward of the Caribbean Islands and the Bahamas while the other enters the Caribbean Sea and flows through the Gulf of Mexico. These waters eventually exit through the Straits of Florida presumably bringing with them petroleum residues and other floating pollutants from the Gulf of Mexico. After being reinforced by the Antilles Current, the combined flow proceeds northward along the continental slope, becoming the Gulf Stream, which is the dominant feature of the circulation of the western North Atlantic, and which carries northward a relatively high loading of tar (Figs. 44—47). In the Labrador Current-dominated waters to the west and north of the Gulf Stream, concentrations decreased abruptly. Indeed, it was repeatedly demonstrated during this study that, on proceeding south from Nova Scotia, a very marked and abrupt increase in tar concentration was always associated with the abrupt increase in temperature that indicated that the boundary of the Gulf Stream was reached. By comparison, the flow of cold, unpolluted waters of the Labrador Current tends to maintain a much lower degree of pollution of the shelf waters off eastern Canada and the northeastern United States than would otherwise be the case.

As the Gulf Stream flows northward the current becomes less well-defined and is characterized by a complex system of variable and transient branches, countercurrents and eddies. These probably account for the complexities observed in the tar concentration distribution in this area of the western North Atlantic (Figs. 44—47). As the Gulf Stream proceeds south of Newfoundland, it assumes a more easterly direction as it interacts with the Labrador Current and its burden of tar is carried in an easterly direction across the Atlantic. East of the Grand Banks the current begins to divide. One branch continues on its easterly course forming the Azores and Portugal Currents which, in turn, proceed in a southerly direction as the Canary Current, and eventually becoming, once again, the North Equatorial Current to complete the gyre. Although this study did not afford an opportunity to study the eastern portion of the gyre in detail, Ehrhardt and Derenbach (1977) recently reported concentrations of 0·007 to 20·5 $mg/m^2$ in 22 samples collected on a transect between Portugal and the Canary Current. In addition, Heyerdahl's (1971) description of his passage along the Canary and North Equatorial Currents leaves little doubt of the extent of oil pollution in the eastern North Atlantic.

In addition to the section of the Gulf Stream which flows toward Europe, another branch flows northeasterly as the North Atlantic Current to a region south of Iceland where it also splits. No data are as yet available concerning the presence or absence of tar in the main portion of the current which continues northeastward past Scotland and then proceeds parallel to the coast of Norway. The second branch veers north and west to become the Irminger Current and forms a minor counterclockwise gyre in the Labrador Sea south of Greenland. Samples collected in the Labrador Sea

* A detailed listing of the original data is available elsewhere (Levy and Moffatt, 1975).

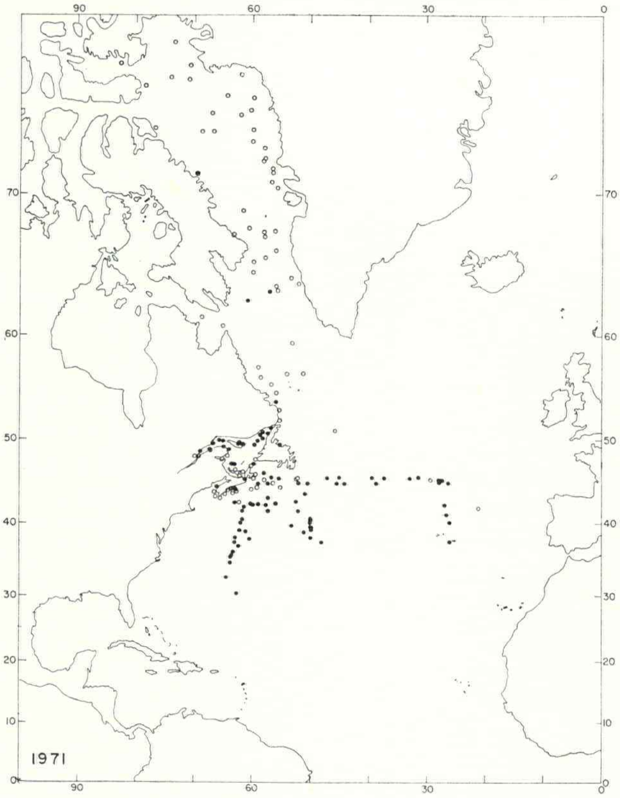


Figure 40. Station plot 1971. Open circles – tar absent; closed circles – tar present.

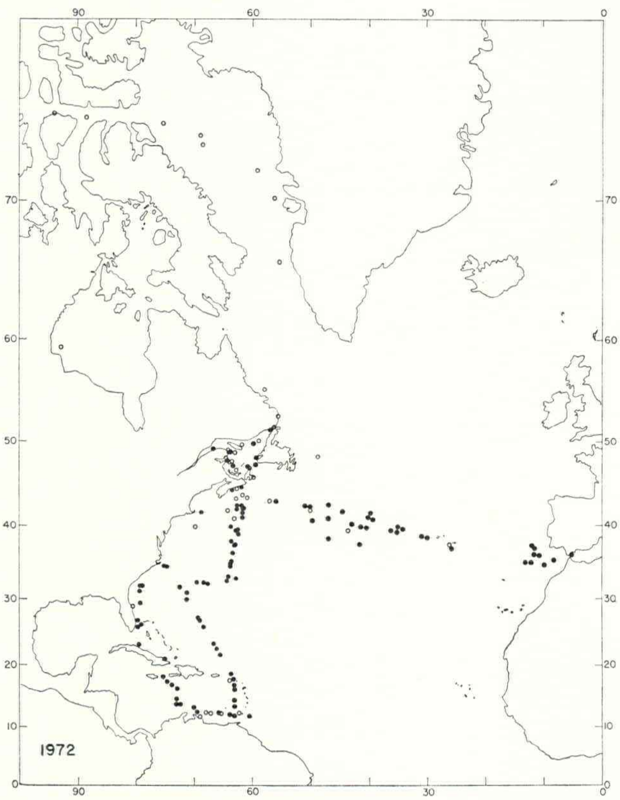


Figure 41. Station plot 1972. Open circles – tar absent; closed circles – tar present.

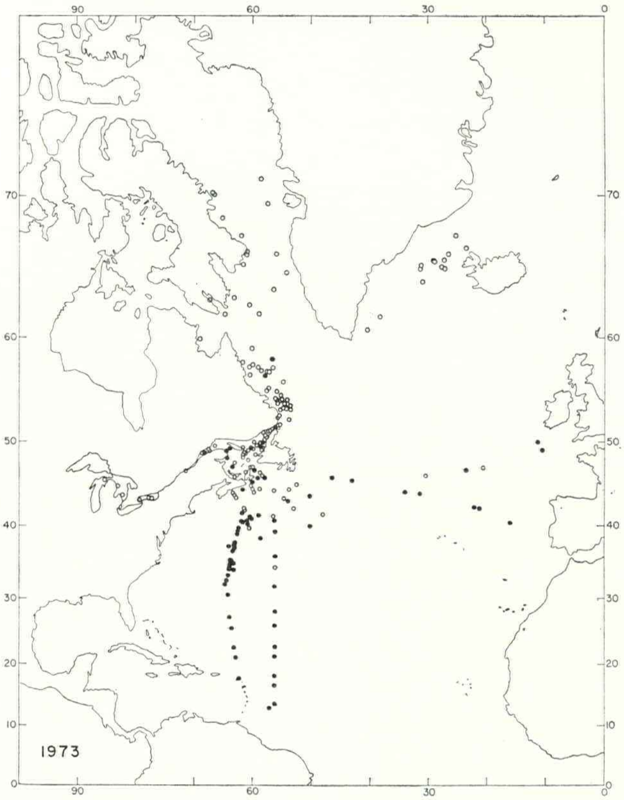


Figure 42. Station plot 1973. Open circles – tar absent; closed circles – tar present.

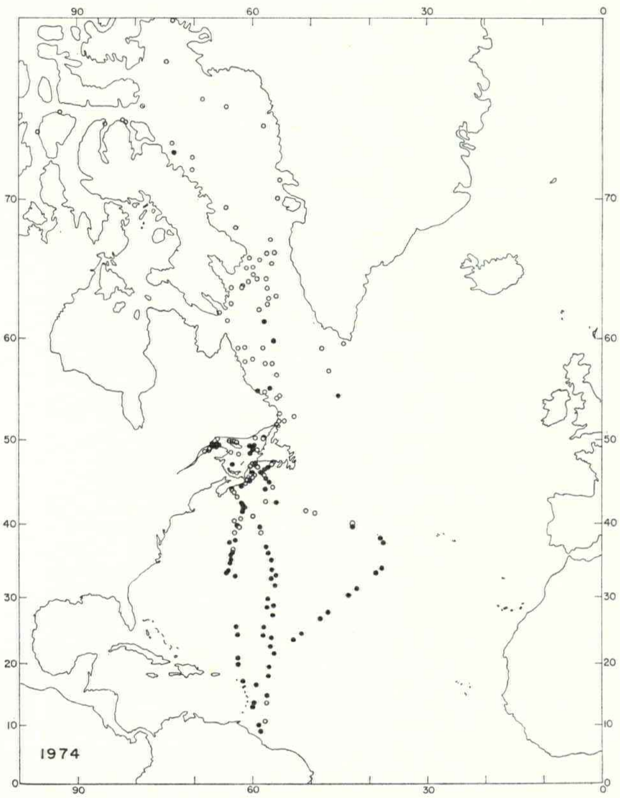


Figure 43. Station plot 1974. Open circles – tar absent; closed circles – tar present.

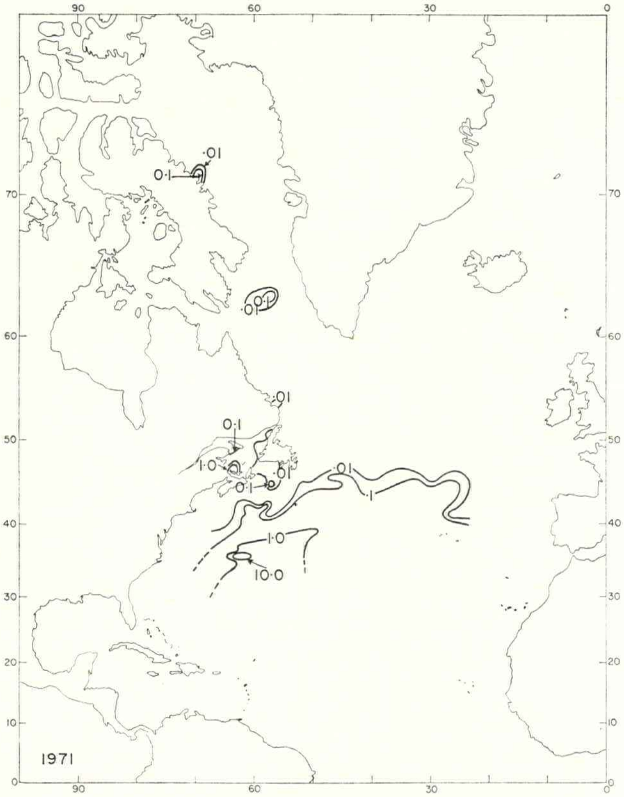


Figure 44. Contour map of tar distribution, 1971.

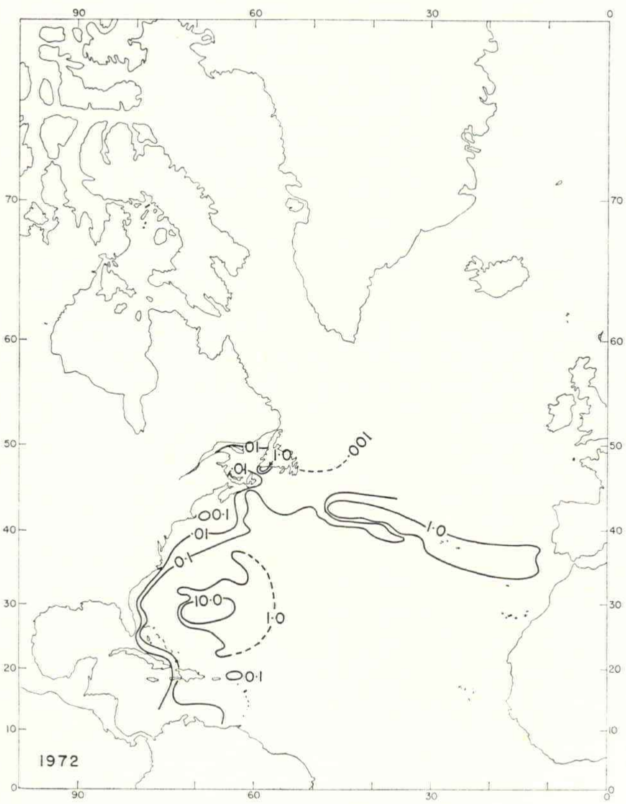


Figure 45. Contour map of tar distribution, 1972.

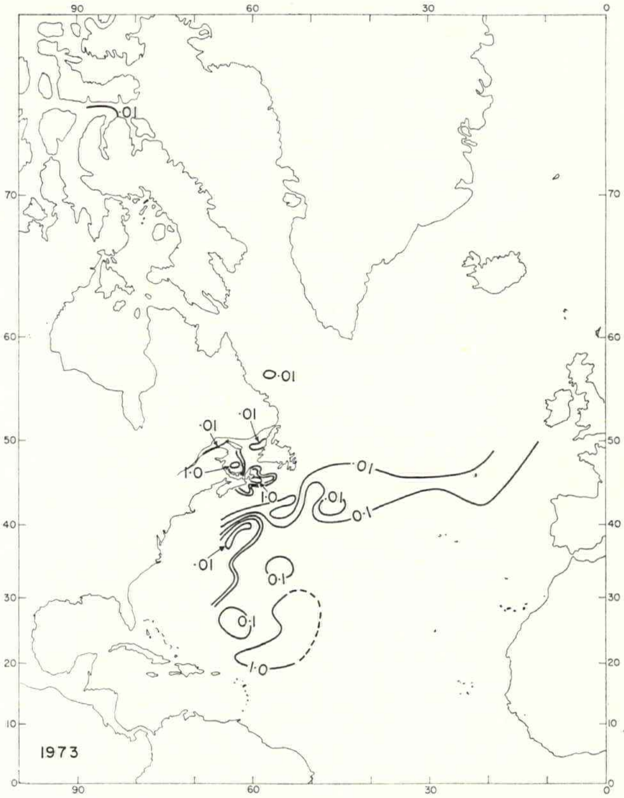


Figure 46. Contour map of tar distribution, 1973.

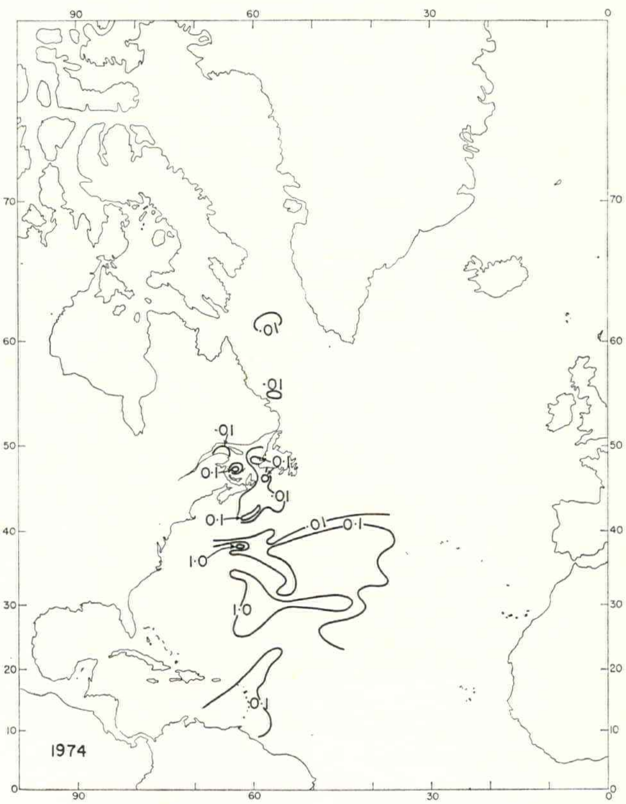


Figure 47. Contour map of tar distribution, 1974.

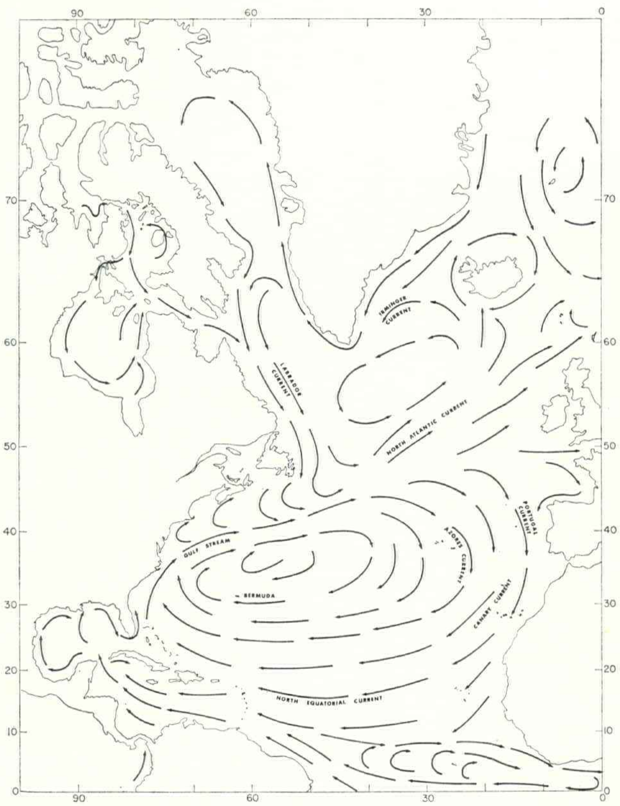


Figure 48. Major surface currents of the North Atlantic.

during this study were free from any evidence of tar pollution. Similarly, the waters which flow southward along the east coast of Greenland entering Davis Strait along the Greenland side and exiting on the Canadian side as the Labrador Current were found to be essentially free from floating petroleum residues. Also free from tar pollution were the waters of Baffin Bay and the water exiting from the Canadian Archipelago. In these areas the only evidence of oil was in the vicinity of ports or areas through which ships had recently passed.

The data collected so far in this study demonstrate that the pollution of the North Atlantic by tar and floating oil is associated primarily with the Sargasso Sea and the Gulf Stream system, while Ehrhardt and Derenbach's (1977) measurements and Heyerdahl's (1971, 1971b) observations suggest that comparable, or even higher, levels of surface pollution are present in the Canary and North Equatorial Currents. It may be concluded, therefore, that most, if not all, of the gyre is affected. It might be further surmised that the very resistant portions of the tar could make one or even more complete circuits around the gyre before weathering processes have reached the stage where the residues disappear completely from the surface of the ocean, being "trapped" there in much the same way as the Sargassum weed.

It would seem possible also that oil released or spilled as far away as the Cape of Good Hope region might be carried by the Benguela Current northwards and thence westward across the Atlantic by the South Equatorial Current eventually entering the North Atlantic gyre. Further, it might be anticipated that the Atlantic to the west of Africa and the corresponding gyre in the South Atlantic might also harbour significant amounts of tar pollution as a result of the large volume of oil being transported along the Persian Gulf-Europe route since the closing of the Suez Canal.

The strong association observed in this study between the distribution of tar and the surface current systems in the North Atlantic is supported by U.S. Coast Guard observations at the North Atlantic Ocean Weather stations (McGowan, Saner and Hufford, 1974). They, too, observed virtually no pollution in the waters between Greenland and Labrador, progressively higher levels in the mid-Atlantic regions of the North Atlantic Current and Gulf Stream and the highest levels in the Sargasso Sea.

It is not entirely by coincidence that the highest levels of tar pollution in the North Atlantic are present in the southern regions and are associated with these current systems. As indicated in Figure 49, the major flow of petroleum through the North Atlantic takes place primarily in a south-to-north direction from the producing areas of Venezuela and the Middle East to consumers in North America and Europe, with a comparatively much smaller movement of oil across the Atlantic. Since it is along the tanker routes where a major portion of the input from marine transportation occurs and since most of the oil which passes over the North Atlantic is consumed by the industrialized and densely populated countries of western Europe and eastern North America, it would be expected that a large portion of the losses associated with this consumption would eventually find its way into the North Atlantic gyre.

## CONCLUDING REMARKS

The results of this study provide an overview of the distribution of tar on the surface of the North Atlantic and how the distribution is related to surface circulation and areas of inputs. This picture is by necessity an oversimplification, because superimposed upon it are many perturbations arising from many highly variable and transient local and seasonal phenomena. While it is appreciated that there are still many gaps to be filled before anything approaching a complete understanding of the extent of high seas oil pollution is achieved, this study provides the essential "first step".

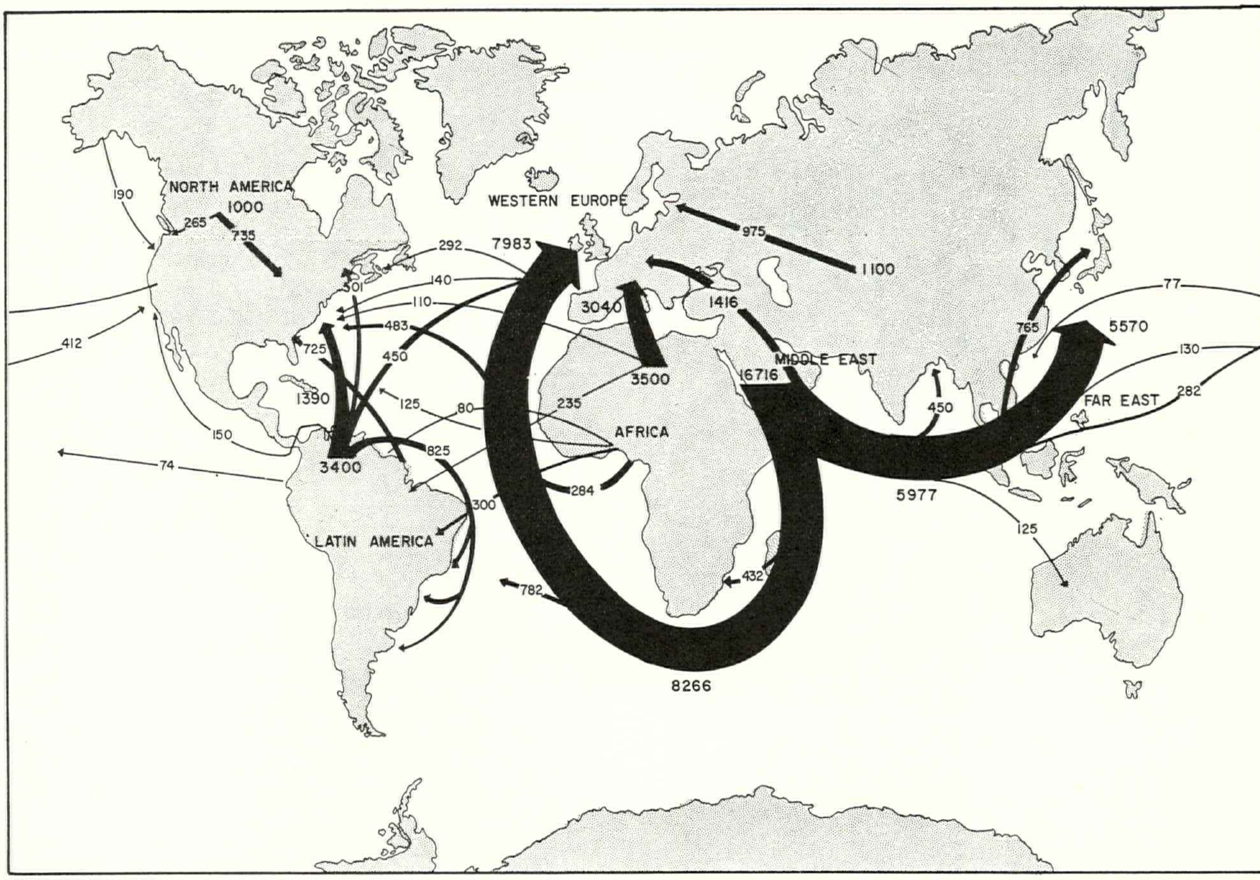


Figure 49. World flow of oil in thousand b/d (1972) (from *International Petroleum Encyclopedia*, 1973).

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