

## Summer Distribution of Bowhead Whales, *Balaena mysticetus*, Relative to Oil Industry Activities in the Canadian Beaufort Sea, 1980-84

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**ABSTRACT.** Aerial surveys in 1980-84 showed that summer distribution of bowheads in the Beaufort Sea varied markedly between years. Distribution varied both outside and within the "main industrial area" (MIA), the area of island construction, drilling and intensive ship and helicopter traffic. Numbers of bowheads in the MIA were high in 1980, lower in 1981, near zero in 1982 and very low in 1983-84. The few whales in the MIA in 1983-84 were mainly near its edges, contrary to 1980-81. These data, plus limited evidence from 1976-79, indicate that bowheads were numerous in the centre of the MIA in 3 of 5 years from 1976-80 (1976-77, 1980) vs. 0 of 4 years from 1981-84. One hypothesis is that progressively increasing industrial activities affected bowhead distribution after 1980. However, bowheads probably also react to variations in their zooplankton prey, which may be affected by year-to-year changes in oceanography and weather. Influences of natural factors on zooplankton and bowheads need to be better understood in order to assess whether oil exploration caused any of the observed changes in bowhead distribution.

**Key words:** bowhead whale, *Balaena mysticetus*, Beaufort Sea, oil exploration, seismic exploration, aerial surveys

**RÉSUMÉ.** Des relevés aériens effectués entre 1980 et 1984 ont montré que la répartition estivale des baleines franches dans la mer de Beaufort varie nettement d'année en année. Elle varie à la fois à l'extérieur et à l'intérieur de la "zone industrielle principale" (ZIP), qui est la zone de construction de l'île, de forage et de circulation intense de bateaux et d'hélicoptères. Le nombre de baleines franches dans la ZIP était élevé en 1980, plus bas en 1981, près de zéro en 1982, et très bas en 1983 et 1984. Les quelques baleines présentes dans la ZIP en 1983 et 1984 étaient principalement à la périphérie, contrairement à 1980 et 1981. Ces données, jointes à des évidences plus limitées de 1976 à 1979, indiquent que les baleines franches étaient nombreuses au centre de la ZIP pendant 3 années sur 5, allant de 1976 à 1980 (1976, 1977 et 1980), par rapport à aucune année sur les quatre allant de 1981 à 1984. On avance l'hypothèse que les activités industrielles progressivement croissantes ont affecté la répartition des baleines franches après 1980. Cependant, les baleines franches ont probablement réagi aussi aux variations de zooplancton qui constitue leur nourriture et qui peut être affecté par les changements qui ont lieu d'année en année dans l'océanographie et le climat. Il est nécessaire de mieux comprendre l'influence des facteurs naturels sur le zooplancton et les baleines franches afin d'évaluer si l'exploration pétrolière a provoqué l'un quelconque des changements observés dans la répartition de ces baleines.

**Mots clés:** baleine franche, *Balaena mysticetus*, mer de Beaufort, exploration pétrolière, exploration sismique, relevés aériens

### INTRODUCTION

The western arctic (= Bering Sea) population of bowhead whales winters in the Bering Sea, summers in the Canadian Beaufort Sea and Amundsen Gulf and migrates around northern and western Alaska in spring and autumn (Fig. 1, inset). The population was severely depleted by 1914, when commercial whaling of bowheads ended. The western arctic population of this endangered species is now estimated to be about 4400 individuals (I.W.C., 1986).

The area of offshore oil exploration in the Canadian Beaufort Sea is in the south-central part of the bowheads' summer range (Fig. 1). In 1976, construction of artificial islands extended offshore into waters where bowheads occur, and drill ships began operating. These activities increased from 1976 to 1984. By 1983-84, 5 drill ships, 2 drilling caissons, 5-6 sea-going dredges, 9-10 helicopters, 3-4 seismic exploration ships, 4 icebreakers, about 10 supply ships and many support vessels were in use.

Bowheads have been seen within a few kilometres from drill sites, dredges, seismic vessels and other boats, within the areas ensounded by their underwater noise. However, bowheads usually interrupt their activities and swim rapidly away from boats that approach within 1-4 km. Less dramatic avoidance reactions sometimes occur at the onset of seismic exploration, drilling or dredging sounds (Richardson *et al.*, 1985b, 1986).

It is not known whether these brief behavioural reactions have long-term negative consequences. One potential long-term effect that might be detectable is displacement. Gray whales

(*Eschrichtius robustus*) apparently were displaced from a wintering lagoon when ship traffic and other human activities intensified and returned several years later when ship traffic decreased (Gard, 1974; Bryant *et al.*, 1984). Less convincing cases of suggested displacement involve other gray whale wintering areas and migration routes (Rice, 1965; Wolfson, 1977; Dohl and Guess, 1979), humpback whale (*Megaptera novaeangliae*) wintering and feeding areas (Norris and Reeves, 1978; MMC, 1979/80; Bryant *et al.*, 1981) and whales in areas of heavy ship traffic off Japan (Nishiwaki and Sasao, 1977). Most of these data on possible long-term displacement are equivocal (Richardson *et al.*, 1983). Some whales continue to use areas where they are hunted or exposed to heavy vessel traffic each year (Mitchell, 1974; Brodie, 1981a; Sorensen *et al.*, 1984).

Before 1980, the only data about summer distribution of western arctic bowheads were the 1890-1914 records from commercial whalers, plus recent incidental sightings. Those records showed that bowheads migrate eastward into the Canadian Beaufort Sea in May and June (Fraker, 1979; Braham *et al.*, 1980). Most sightings in early summer were in western Amundsen Gulf and the extreme eastern Beaufort Sea — east of the area of present offshore oil exploration (Townsend, 1935; Sergeant and Hoek, 1974; Fraker *et al.*, 1978; Fraker and Bockstoce, 1980). Bowheads seemed to spread gradually westward off the Tuktoyaktuk Peninsula, Mackenzie Delta and Yukon coast in August, although they might also have been moving south from areas of pack ice farther north. In September, bowheads apparently moved west between Cape Bathurst

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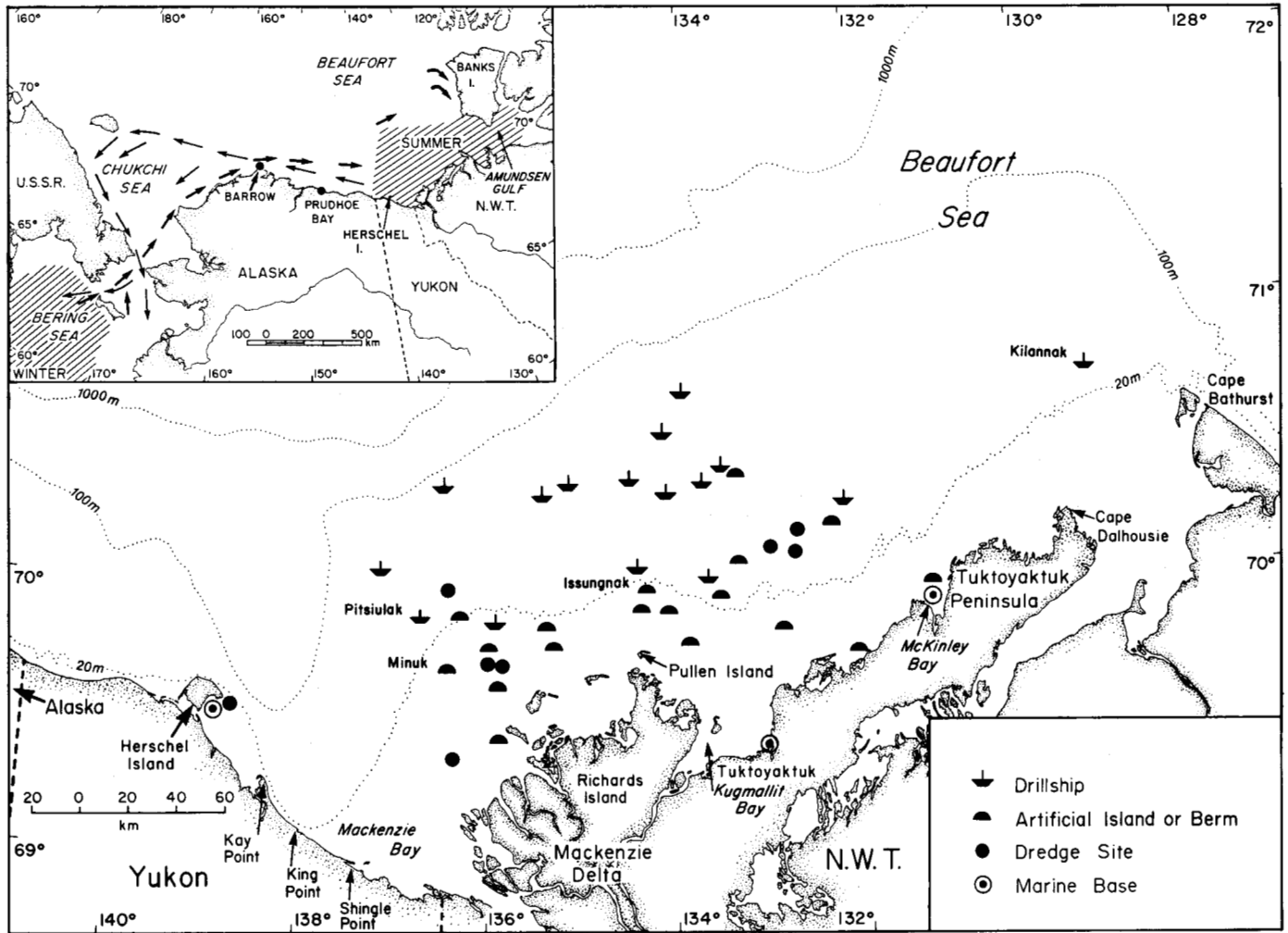


FIG. 1. The eastern Beaufort Sea, study area for this project, showing the main sites of offshore industrial activity in August and early September 1980-84. No more than five drill ships were operating at any one time. Inset: The overall range of western arctic bowheads.

and the Alaska border ( $128^{\circ}$ - $141^{\circ}$ W; Sergeant and Hoek, 1974), sometimes concentrating near the Yukon coast (Fraker and Bockstoce, 1980). The latest sightings in Canadian waters were in early October (Fraker and Bockstoce, 1980). Thus, pre-1980 data suggested that bowheads were most common in the now-industrialized area during August and early September.

In 1980-84, numbers, distribution and movements of bowheads in much of the Canadian Beaufort Sea were documented by systematic and other aerial surveys. The results provide a far more detailed view of summer distribution and movements of bowheads than was available up to 1979 (*cf.* Fraker and Bockstoce, 1980; Hazard and Cabbage, 1982). The 1980-84 data summarized here show major year-to-year differences in distribution and numbers of bowheads within the area of offshore oil exploration. We assess whether the trends in summer distribution are related to industrial activities.

#### METHODS AND DATA SOURCES

##### *Bowhead Sightings*

Aerial surveys were conducted in the SE Beaufort Sea from early August to early or mid-September of 1980-84, plus major parts of July in 1981 and 1984 (Table 1). At various times, 1-6

high-wing aircraft conducted bowhead studies in our study area ( $127^{\circ}$ - $141^{\circ}$ W). Aircraft included an Islander, a Turbo Commander, Turbo Goose (2) and Twin Otters (several). Field procedures varied; for details, see the reports listed in Table 1. Survey altitudes were 153-610 m. There were 2-4 observers per aircraft. During almost all surveys, Very Low Frequency (VLF) navigation systems were used.

For each year, we mapped survey routes and bowhead sightings during four periods: 1-10, 11-21 and 22-31 August and 1-10 September. Figure 2 shows the 22-31 August data; Richardson *et al.* (1985a) show corresponding maps for other periods. We mapped all sightings along defined survey routes, whether or not the sightings were classified as on- or off-transect in the original reports. In a few 10 d periods, there were so many aerial surveys in certain "intensive coverage areas" that it was impractical to show every flight line. In these areas only the bowhead sightings are shown.

The maps provide only a rough indication of relative abundance in different areas and must be interpreted with caution. Survey procedures, survey effort and detectability of whales all varied, and non-systematic surveys were concentrated in areas with many bowheads. Some whales undoubtedly were mapped more than once in a 10 d period, especially in areas with much

TABLE 1. Systematic and non-systematic aerial surveys of bowhead whales in the Canadian Beaufort Sea, 15 July-20 September 1980-84<sup>1</sup>

	1980	1981	1982	1983	1984
Systematic surveys	Renaud & Davis (1981) 6 Aug-4 Sept 7 d/6258 km <sup>1</sup>	Davis <i>et al.</i> (1982) 18 July-14 Sept 28 d/37 745 km <sup>8</sup>	Harwood & Ford (1983) 18 Aug-13 Sept 9 d/7442 km	McLaren & Davis (1985) 19 Aug-11 Sept 9 d/7045 km	Harwood & Borstad (1985) 18 Aug-18 Sept <sup>2</sup> 10 d/11 170 km
Behaviour & disturbance	Richardson (1985) <sup>3</sup> 3-31 August 16 f/101 h	Richardson (1985) <sup>3</sup> 27 July-8 Sept 27 d/32 f/117 h	Richardson (1985) <sup>3</sup> 1-31 August 19 d/27 f/122 h	Richardson (1985) <sup>3</sup> 1 Aug-1 Sept 18 d/28 f/114 h	Richardson (1985) <sup>3</sup> 1 Aug-3 Sept 23 d/33 f/140 h
Alaskan surveys extending into Canada <sup>5</sup>	Ljungblad (1981) <sup>5</sup> 28 July-24 Oct 8 f/8 d <sup>6</sup>	Ljungblad <i>et al.</i> (1982) <sup>5</sup> 15 Aug-20 Sept 10 f/10 d	Ljungblad <i>et al.</i> (1983) <sup>5</sup> 2 Aug-15 Oct 16 f/16 d <sup>6</sup>	Ljungblad <i>et al.</i> (1984 a, b, unpubl.) <sup>5</sup> 2 Aug-5 Oct; 29 f/23 d	Ljungblad <i>et al.</i> (1985) <sup>5</sup> 17 July-11 Oct 24 f/21 d <sup>6</sup>
Photogrammetric & other studies	Hobbs & Goebel (1982) 21 July-12 Sept 13 f/13 d <sup>7</sup> Norton Fraker & Fraker (1981) 24 July-9 Aug 3 f/3 d	part of Davis <i>et al.</i> (1982); see above	Davis <i>et al.</i> (1983) 12 Aug-5 Sept 15 d/72 + h/>8781 km	Cubbage <i>et al.</i> (1984) 7 Aug-6 Sept 24 f	Davis <i>et al.</i> (1986) 14 Aug-14 Sept 23 d/90+ h D. Rugh (U.S. Nat. Mar. Mamm. Lab.) <sup>4</sup> 13-17 Aug 4 d/4 f

<sup>1</sup>Survey effort is summarized in terms of *d*, days of surveying; *f*, number of offshore flights; *h*, hours of surveying; *km*, kilometres of straight-line transects.

<sup>2</sup>Harwood and Borstad (1985) also summarize four July surveys (5 July-2 August 1984, 12 d, approx. 6400 km) of the Alaska border to Cape Bathurst area.

<sup>3</sup>Distributional data obtained during the behavioural study have not been presented in detail elsewhere.

<sup>4</sup>Unpublished distributional data are mapped here through the cooperation of the cited investigator.

<sup>5</sup>Flights that extended east of 141°W are considered here.

<sup>6</sup>Flights after 20 September are not counted.

<sup>7</sup>Excludes flights also mapped by Ljungblad (1981).

<sup>8</sup>Includes coverage in Amundsen Gulf as well as Beaufort Sea *per se*.

survey coverage. Conversely, lack of sightings along a survey line does not prove that whales were totally absent, since an average bowhead was submerged 73% of the time (Richardson, 1985). To reduce these problems and summarize the data, detailed maps (e.g., Fig. 2) were used to prepare summary maps of the relative abundance of bowheads in different areas during early and late August each year.

### Industrial Activities

For 1 August-10 September of each year (1980-84), we mapped the routes along which seismic vessels operated (e.g., Fig. 3A). Noise impulses emitted by seismic vessels are the most intense underwater sounds routinely created by the oil industry and are often detectable up to 25-90 km away (Richardson *et al.*, 1983, 1986; Greene and Richardson, in press). Locations of seismic lines were provided by geophysical and oil companies, often corroborated by our observations of seismic vessels at sea. Locations of a few proprietary lines are unknown to us. Maps of specific seismic lines (e.g., Fig. 3A) were used to map general areas with seismic exploration each year.

For each year, we also mapped offshore industrial sites active in the 1 August-10 September period, plus ship traffic (e.g., Fig. 3B). The main site-specific activities were dredging, island or berm construction, drilling from drill ships or islands and island clean-up. In compiling the number of vessel trips along each route, we included supply ships, crew boats, tug/barge trains, dredges, icebreakers and drill ships moving between sites. Seismic, sounding and research vessels were excluded. All major offshore operators gave us access to their records (see Acknowledgements), but the records did not list every vessel movement, and mapped routes are approximations. For 1981-84, helicopter traffic offshore was mapped in the same way as boat traffic (e.g., Fig. 3C; data not available for 1980). Areas with frequent helicopter and boat traffic were similar.

We defined the "main industrial area" (MIA) to be the area of site-specific industrial activities and associated vessel and

helicopter traffic, excluding the few vessel trips to points east or west of the area of oil exploration. We mapped the MIA each year based on the detailed site, vessel traffic and helicopter traffic maps (e.g., 1984 data in Figs. 3B, 3C). Corresponding industrial activity maps for 1980-83 are shown in Richardson *et al.* (1985a). The MIA was not as large as the more extensive area where seismic exploration took place (Fig. 3A vs. 3B, 3C). For each year, the MIA and the area of seismic exploration were overlain onto summary maps of bowhead distribution (Figs. 4, 5) to help us interpret the occurrence of bowheads within as opposed to outside the areas of industrial operations.

## RESULTS

### Industrial Activities

Artificial islands had been built off the Mackenzie Delta before 1976, but only in very shallow water (Marks, 1982/83). The first artificial islands in water as deep as 13-18 m, where bowhead whales could be encountered, were built north of the delta in 1976-79. Those islands were constructed by barging dredged sand from shallower waters and by a suction dredge operating at the island sites. The first three drill ships arrived in 1976 and a fourth in 1979. The drill ships operated in deeper waters, generally 45-100 km north of the delta but to a lesser extent farther east (off eastern Tuktoyaktuk Peninsula) and west (off Yukon coast west of Herschel Island). Richardson *et al.* (1985a) mapped the industrial sites active in 1976-79.

The general level of industrial activity increased gradually until 1983 and then levelled off or began to decrease. Offshore dredging activity increased from one suction dredge in 1980 to two suction and four hopper dredges in 1982-83; there were four hopper dredges in 1984. Suction dredges remain near the construction site; hopper dredges travel widely (Roberts and Tremont, 1982). Dredges constructed artificial islands and underwater berms increasingly far offshore: out to the 18 m contour in 1980, 31 m in 1981 and 45 m in 1982-83. Four drill

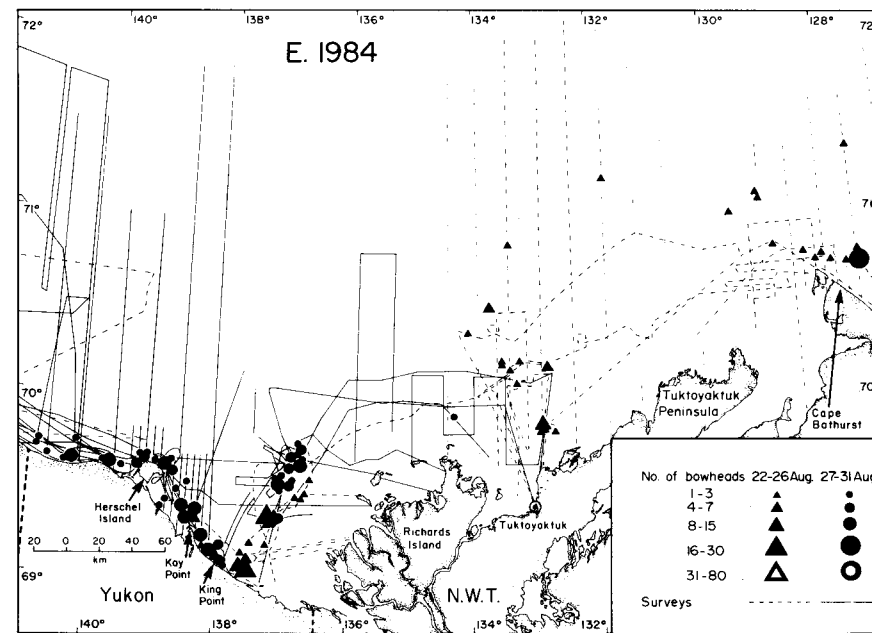
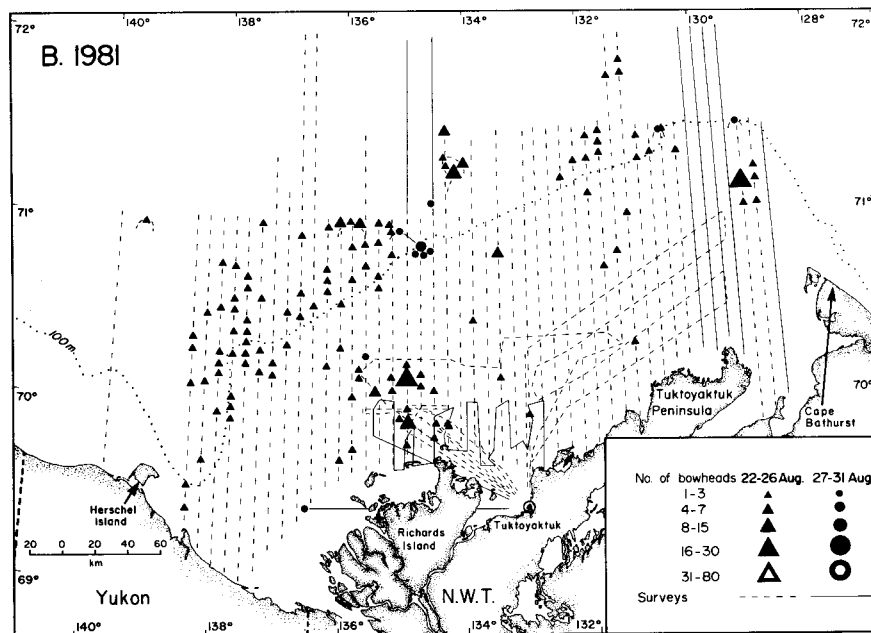
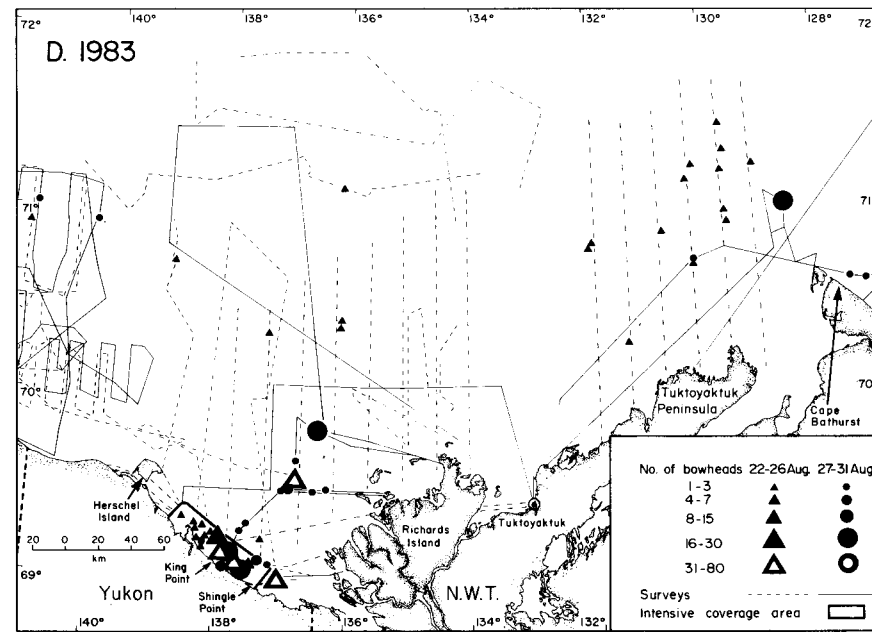
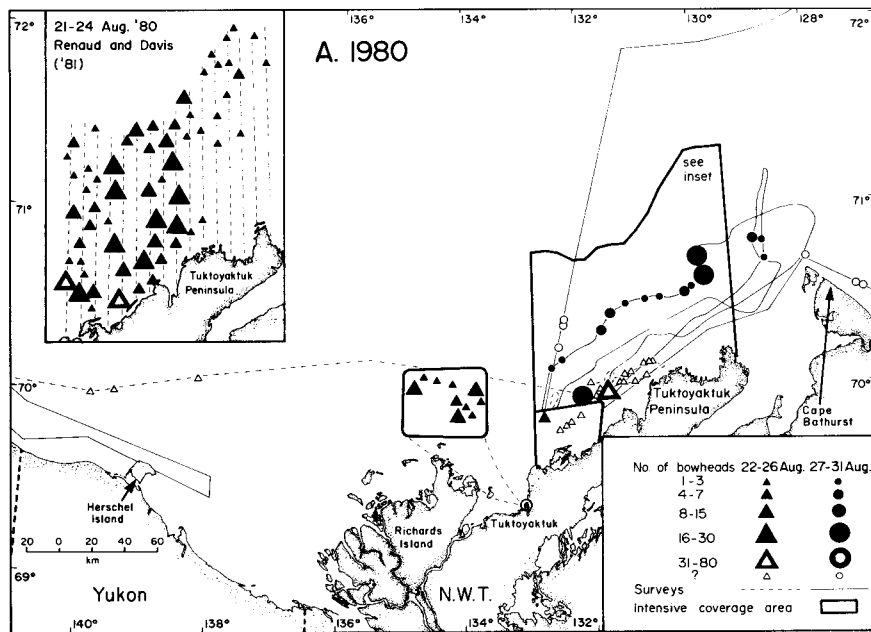


FIG. 2 (above and below). Bowhead sightings and survey routes in the 22-31 August periods of 1980-84. Richardson *et al.*, 1985a, includes maps for other ten-day periods.

ships operated in 1980-82 and five in 1983-84. The number of specialized industry-owned icebreakers supporting the drill ships increased from one in 1980 to four in 1984, excluding supply ships with some icebreaking capability. The precise number of supply, crew and tug boats working each year is unknown, but was at least 37 in 1983. The number of twin-engine turbine-powered helicopters operating offshore increased from about five in 1980 to ten in 1983 and was eight or nine in 1984.

Most island construction and drilling was north of the Mackenzie Delta and western Tuktoyaktuk Peninsula in all years. However, the outline of the MIA varied within and between years, depending on the locations of active sites (Figs. 4, 5). For example, in 1981 a drill ship operated unusually far to the east (Kilannak, Fig. 1), and dredging occurred as far west as Herschel Island. In 1984, vessel and helicopter traffic extended west to an anchorage near Herschel Island.

Marine seismic exploration occurred in the Canadian Beaufort Sea each summer from 1971 to 1984. Each seismic vessel introduces an intense noise pulse into the water every several seconds (Richardson *et al.*, 1986). In 1980-84, seismic exploration occurred across much of the Canadian Beaufort, including both the MIA and other areas farther east or west (Figs. 3A, 4, 5). In 1980-84, 3-5 seismic vessels operated in the area each year. Additional Alaska-based vessels worked near the Alaska-Yukon border in some years.

#### Bowhead Distribution

**1980:** In early August 1980, many bowheads moved into shallow water north of the Mackenzie Delta (Fig. 4A). Many socialized, dove and fed <5 km from a dredge and support vessels

at Issungnak artificial island (Fig. 1; Richardson *et al.*, 1985b). Seismic exploration also occurred nearby (Fig. 4A). In mid-August, bowheads were still numerous there, and many appeared farther east off the Tuktoyaktuk Peninsula. Industrial activity was less intense in the latter area, but some whales were exposed to strong noise pulses from a seismic vessel (Richardson *et al.*, 1986).

By late August 1980, very large numbers of bowheads were off the western part of the Tuktoyaktuk Peninsula, and others remained near Issungnak. Renaud and Davis (1981) estimated that 755 bowheads were in their survey area (Fig. 2A, inset), with no allowance for missed or submerged whales. The size of this concentration was unique in the 5 yr of study. Based on correction factors for missed whales derived in 1981 (Davis *et al.*, 1982), over half of the western arctic bowhead population apparently was in shallow waters ( $\leq 50$  m) off the Tuk Peninsula, many within the MIA (Fig. 5A).

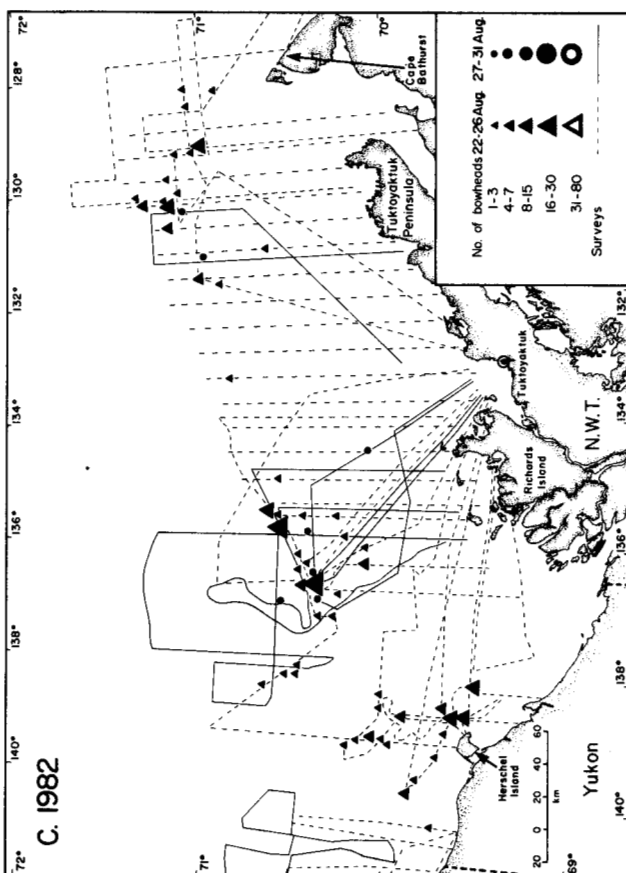
In early September 1980, bowhead numbers off the Tuk Peninsula were about one-third those in late August, all in water at least 25 m deep. Most were far from industrial activity, but a few were near seismic lines (Richardson *et al.*, 1985a). Numbers off the delta were much reduced, but whales were present near Herschel Island. Bowheads were first seen off Alaska on 4 September and were numerous there by 14 September (Ljungblad, 1981).

**1981:** Survey coverage was much more comprehensive in 1981. Most bowheads remained farther offshore than in 1980. In late July, most were either far offshore in pack ice or in Amundsen Gulf. In early August, many moved south onto the outer continental shelf off the Mackenzie Delta, with lesser numbers off the Tuk Peninsula (Fig. 4B). Few whales were in the MIA, but some of those farther offshore were exposed to seismic pulses. None was seen near Issungnak, where whales had been abundant in early August 1980.

In mid- and late August, some bowheads were in shallow water off the delta, but most were widely distributed near and beyond the 100 m contour (Figs. 2B, 5B). Off the Tuk Peninsula, bowheads were much scarcer and farther offshore than in 1980. Some were <15 km from Issungnak island and a nearby drill ship, but most were north or west of the major industrial sites, contrary to 1980. Seismic work extended north of the MIA, and more bowheads probably were exposed to seismic pulses than to other industrial activities (Fig. 5B). On 24-26 August, the captain of GSI *Mariner*, operating off the Tuk Peninsula, saw groups of 2-4 bowheads about 2-5 km from his seismic ship.

In early September, most bowheads were still in Canadian waters, with many off the Tuk Peninsula and Herschel Island and lower densities in the MIA. Some whales in or near the MIA probably were exposed to seismic pulses; whales near the Alaska border definitely were. The first autumn sighting off Alaska was on 7 September.

**1982:** In 1982, unlike 1981 and especially 1980, almost all bowheads were far enough offshore or west to be outside the MIA. In early August, the only sightings in the Canadian Beaufort Sea were on the outer shelf west of the MIA (Fig. 4C). Bowheads were present west to 144°W in the Alaskan Beaufort in early August (Ljungblad *et al.*, 1983). In mid-August 1982, there was a major concentration of bowheads near Herschel Island, but again virtually none in the MIA. In both early and mid-August, few whales were in water <50 m deep; whales near Herschel Island and Cape Bathurst were in areas where deep



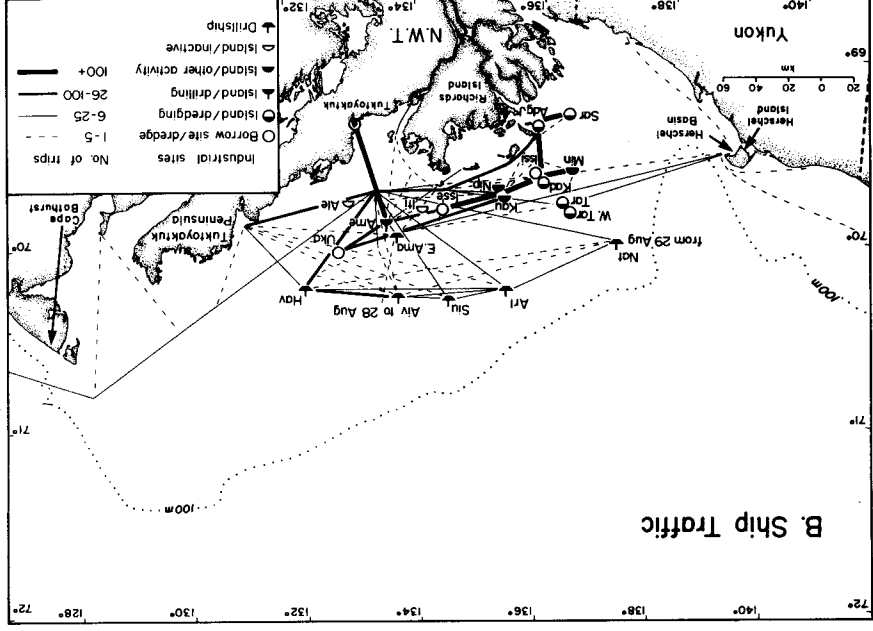
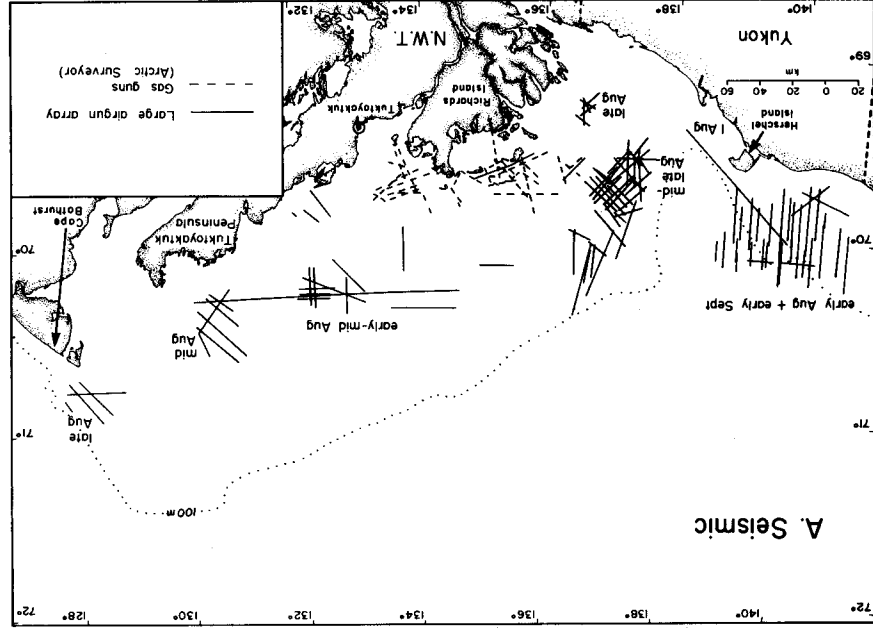
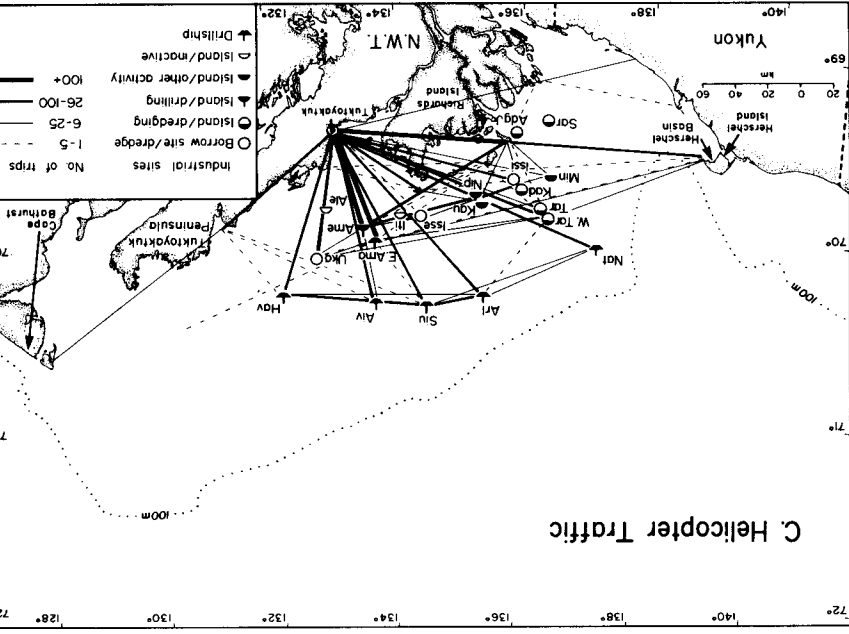


FIG. 3. Industrial activities in the eastern Beaufort Sea, 1 August-10 September 1984. A: Seismic traffic intensity and offshore industrial sites. Richardson *et al.*, 1985a, includes similar maps for 1976-83. Abbreviated names of offshore industrial sites are given.

water occurs near shore. Some whales west of the MIA were exposed to seismic impulses (Richardson *et al.*, 1986; Figs. 4C, 5C).

In late August and early September 1982, many bowheads remained off Herschel Island, mainly over 50-200 m depths. Others were far offshore near the shelf break from 128°W to 140°W (Figs. 2C, 5C), with a few at 145°W. Very few were within the MIA, but those near Herschel Island in early September were probably exposed to seismic noise. The main westward migration into Alaska was after mid-September (Ljungblad *et al.*, 1983; Johnson, 1984).

1983: Most bowheads remained outside the MIA again in 1983, but their distribution was very different from that in 1982. In early August 1983, bowheads occurred in deep water far off the western Yukon (Fig. 4D). We saw no bowheads in the MIA, but industry personnel twice reported 1-2 whales near its east edge. Seismic exploration again occurred beyond the MIA, and some whales off the Yukon were exposed to seismic noise (Fig. 4D; Ljungblad *et al.*, 1984a; Richardson *et al.*, 1986).

In mid- and late August 1983, several hundred bowheads were in shallow water along the Yukon coast southeast of Herschel Island, away from industrial activity (Figs. 2D, 5D). Distances from shore ranged from <1 to 15 km, varying daily. This coastal concentration was absent in 1980-82 but was present in some years before 1980 (Fraker and Bockstoce, 1980). Much lower densities of bowheads were found in various offshore areas and in shallow water near the northeast and southwest edges of the MIA (Figs. 2D, 5D). The latter group was 10-12 km from the *Kulluk* drill rig at Pitsiulak (Fig. 1), along a main helicopter route and exposed to seismic pulses.

In early September 1983, bowheads left the Yukon coast. Although migration into Alaskan waters was under way by 3 September, many bowheads remained far to the east, in Franklin Bay (126°W) and off the Tuk Peninsula (Cabbage *et al.*, 1984; McLaren and Davis, 1985). There were again only a few sightings in the MIA, most near its southwest edge.

1984: In 1984, bowheads were somewhat more common near the edges of the MIA than in 1982-83, although much less common than in 1980. Surveys throughout July showed that bowheads began moving onto the outer shelf in late July (depths mainly 51-100 m). Only one bowhead was seen in the MIA during July surveys, but industry personnel reported several July sightings (Harwood and Borstad, 1985). In early August, no bowheads were seen in the MIA, but the few whales east and north of Herschel Island sometimes were exposed to seismic noise (Fig. 4E; Richardson *et al.*, 1986).

From mid-August into September, many whales were along the Yukon coast; they were not exposed to much industrial activity. Whales also occurred along the west edge of turbid Mackenzie River water in central Mackenzie Bay (Fig. 2E). Some were <10 km west of the westernmost artificial island (Minuk, Fig. 1), under a helicopter route to Herschel Basin (*cf.* Figs. 3C, 5E). Also, they were often exposed to strong seismic noise (Figs. 3A, 5E; Richardson *et al.*, 1986). Lesser numbers were north of Tuktoyaktuk, within the MIA but near its east edge. Bowheads were again present east of Cape Bathurst well into September (Davis *et al.*, 1986), after migration into Alaska began.

1976-79: The shallow water north of the eastern Mackenzie Delta and western Tuk Peninsula is one part of the Canadian Beaufort Sea where bowheads were studied before 1980. In 1976-79, M.A. Fraker conducted reconnaissance surveys and

TABLE 2. Bowhead sightings off the eastern Mackenzie Delta and western Tuktoyaktuk Peninsula in the summers of 1976-80<sup>1</sup>

Year	Incidental sightings <sup>2</sup>		Systematic offshore surveys, 1-15 Aug		Dates observed	
	No. of sightings	No. of bowheads	No. of bowheads	Density <sup>3</sup> ( $\times 1000$ km <sup>-2</sup> )	First	Last
1976	15	46	—	—	3 Aug	16 Sept
1977	26	98	—	—	26 July	17 Sept
1978	5	58	1 <sup>4</sup>	0.5	26 July	14 Sept
1979	1	6	1	0.5	8 Aug	9 Sept
1980	18	136	139	41.0	2 Aug	11 Sept

<sup>1</sup>Sources: Fraker *et al.*, 1978; Fraker and Bockstoce, 1980; Richardson *et al.*, 1985a; M.A. Fraker and P. Norton, unpubl. data.

<sup>2</sup>Sightings by industry personnel and biologists, excluding specific studies of bowheads.

<sup>3</sup>Uncorrected density; no allowance for submerged or missed whales.

<sup>4</sup>Plus sightings totalling 4 whales on 26 July 1978.

collected industry sightings (Fraker *et al.*, 1978; Fraker and Bockstoce, 1980). Also, limited systematic surveys were conducted there in 1978-79. This region was within the MIA in 1976-79 as well as in 1980-84.

Bowhead abundance in the MIA varied between years in the late 1970s as well as the early 1980s. In 1976, many bowheads were seen in water <15 m deep during early August (Table 2). About 40 were seen on 10 August alone. Similarly in 1977, there were 26 sightings totalling 98 bowheads in water <15 m deep (Table 2). In 1978, there were several incidental sightings in water 11-18 m deep, but all were after 7 September. Opportunities for incidental sightings in 1978 were similar to those in 1977, when many whales were seen during August. In 1979, there was only one incidental sighting. Systematic aerial surveys north of the delta in late July and early August 1978-79 also detected few bowheads (Table 2). Thus, bowheads were numerous in shallow waters of the MIA in August 1976-77, infrequent until 7 September in 1978 and infrequent in 1979.

## DISCUSSION

Bowhead distribution varied greatly within and between summers, but some patterns are evident. We summarize these patterns before considering whether any trends in distribution are related to industrial activities.

### Seasonal Trends in Distribution

*Late July:* Only in 1981 and 1984 were there extensive surveys in late July. In 1981, more bowheads were in Amundsen Gulf than in the SE Beaufort Sea, but the majority of the population was not found (Davis *et al.*, 1982). Presumably most were far offshore in pack ice, perhaps with some in unsurveyed Alaskan waters. In 1984, bowheads began to arrive in the SE Beaufort Sea late in July; none was seen off Alaska in July 1984.

*Early August:* Distribution in early August differed greatly among years (Fig. 4). In 1980 and perhaps 1976-77, many bowheads moved into shallow ice-free waters north of the Mackenzie Delta in early August. In 1981-84, most remained farther offshore either in or near ice, with specific locations varying among years (Fig. 4; see Richardson *et al.*, 1985a, for ice maps).

*Mid-Late August:* The area of peak whale concentration extended closer to shore in mid-late August than early August.

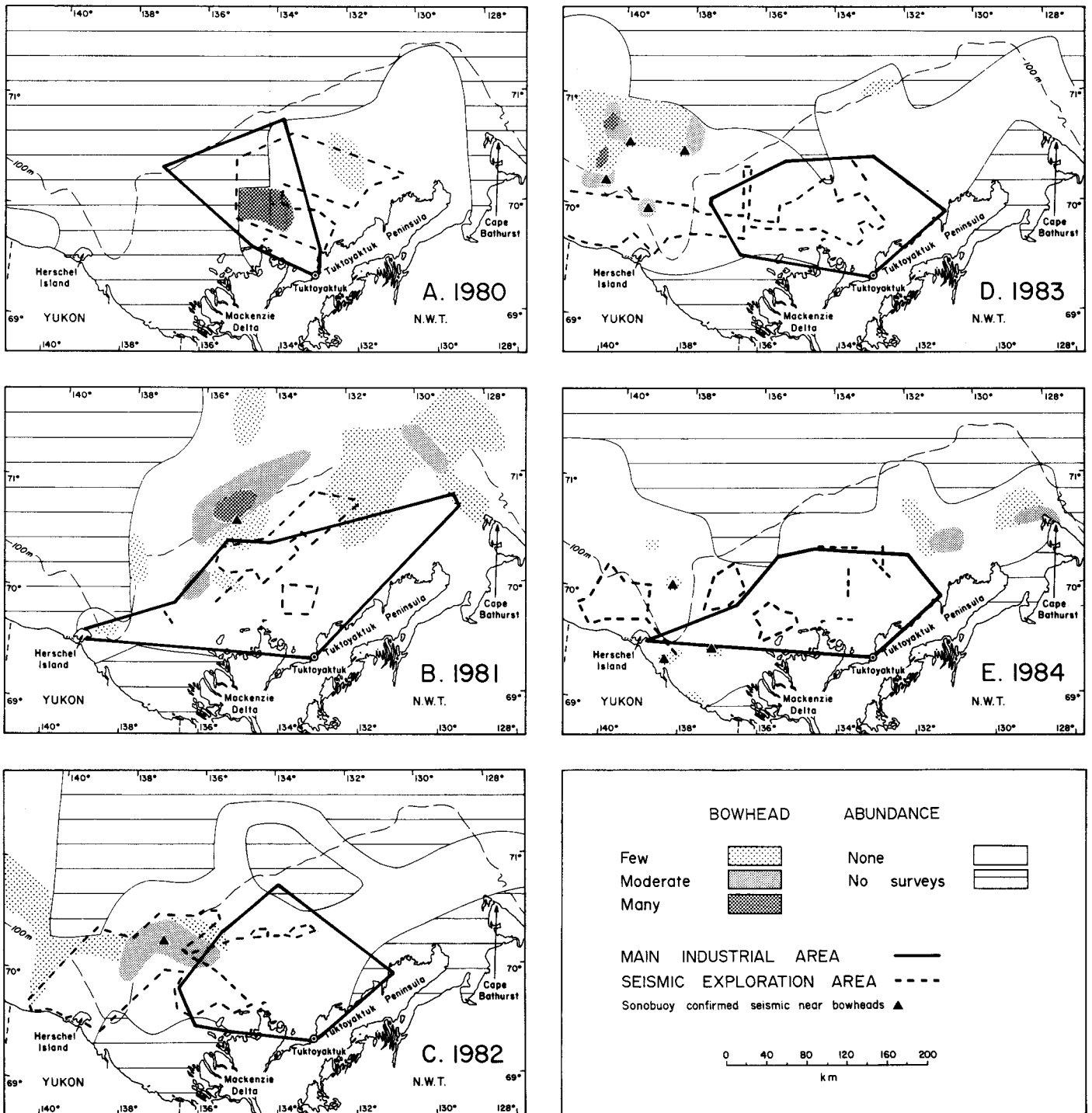


FIG. 4. Distribution of bowheads on 1 - 10 August 1980-84 in relation to the main industrial area on 1 - 10 August. Triangles show locations where sonobuoys dropped near bowheads confirmed that bowheads were exposed to noise pulses from seismic vessels.

In 1980 the shift was slight; whales were already in shallow water in early August. In 1981-84, the shift was more dramatic (Fig. 4 vs. 5). In 1980-81, concentrations occurred north or northeast of the delta, whereas in 1982-84 concentrations occurred farther west. The concentration northeast of the delta in late August 1980 contained more whales than any other group documented in 1980-84. In 1982, many whales were close to Herschel Island, where deep water occurs close to shore. In 1983-84, but not 1980-82, hundreds of bowheads were in

shallow areas in Mackenzie Bay and off the Yukon coast. Thus, movement toward shore occurred each year in mid-late August, but the area of concentration varied.

*September:* Distributions differed less among years in early September than in August. Whales remained over the continental shelf off the Tuk Peninsula in early September each year, although numbers and locations varied. Bowheads were common NE of Herschel Island each year except 1983. In 1984, unlike 1983, bowheads remained near the Yukon coast in



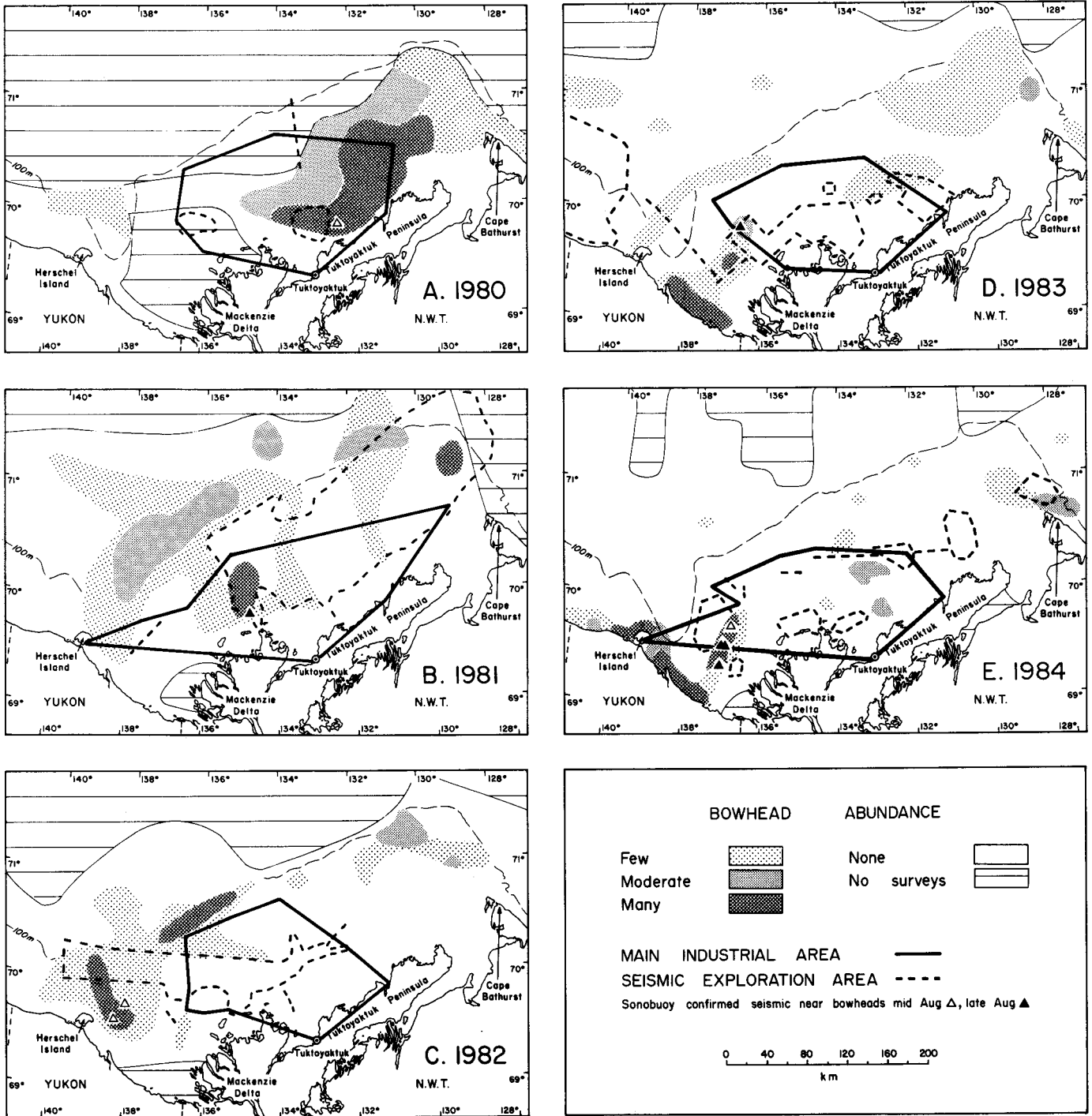


FIG. 5. Distribution of bowheads on 18 - 31 August 1980-84 in relation to the main industrial area on 11-31 August . Bowhead data are primarily from Figure 3 ( 22 - 31 August ) , supplemented by survey coverage on 18 - 21 August . Triangles show locations where sonobuoys dropped near bowheads confirmed that bowheads were exposed to noise pulses from seismic vessels.

September. Some bowheads moved west into the Alaskan Beaufort Sea in early September (Ljungblad *et al.*, 1985), but the main migration into Alaska was later. Bowheads remained as far east as Franklin Bay (126°W) in early to mid-September of all years with surveys (1981, 1983, 1984). There have been a few sightings in Canadian waters in early to mid-October.

*Geographic Areas Where Bowheads Often Concentrate*

In early summer, bowheads seem to concentrate in the western half of Amundsen Gulf, where break-up is early (Fraker, 1979; Reeves and Mitchell, 1985). In 1981, some bowheads apparently moved out of Amundsen Gulf around 1 August.

However, bowheads remain common there, especially in Franklin Bay, in late summer (Davis *et al.*, 1982, 1986; Hazard and Cabbage, 1982; Cabbage *et al.*, 1984; Harwood and Borstad, 1985). Around 1900, the whalers found bowheads near Cape Bathurst all summer (Fraker and Bockstoce, 1980; Bockstoce, 1986). Bowheads also were seen near Cape Bathurst in 1979-84 (Hazard and Cabbage, 1982; this paper). Strong currents and sharp water mass boundaries occur there, and deep water occurs near shore.

The whalers took bowheads in shelf waters (<50 m deep) off the Tuktoyaktuk Peninsula in late summer (Fraker and Bockstoce, 1980). Bowheads still occur there in that season, but dates, specific locations and numbers vary among years. Farther west, bowheads concentrated at the shelf break about 125 km NW and NNW of the delta in 1981-82. The bottom slope is unusually steep there, dropping from 100 to 500 m in <10 km.

During the 1970s, bowheads often were seen in shallow water along the Yukon coast SE of Herschel Island in late summer (Fraker and Bockstoce, 1980). In 1980-82 there was no such concentration, but in 1983-84 many bowheads occurred there. Bowheads were seen N and NE of Herschel Island in early September 1980-81 and starting in mid-August of 1982 and 1984. Bowheads also were found there in late summer around 1900 (Fraker and Bockstoce, 1980). Deep water occurs close to shore off Herschel Island.

#### *Bowhead Distribution Relative to Industry*

Behavioural studies suggest that bowheads react only briefly to transient oil industry activities and to the onset of industrial noises; bowheads may habituate to ongoing noise from distant drilling, dredging or seismic operations (Richardson *et al.*, 1985b, 1986). However, behavioural studies cannot determine whether fewer whales move into an area if industrial activity is present, or whether they are less likely to return to such an area in subsequent years. Large-scale surveys conducted over a number of years provide a way to address these questions.

*Area of Seismic Exploration:* Seismic exploration occurred over a broader area than drilling, dredging and support traffic in 1980-84 (Figs. 3, 4, 5). Also, underwater noise was detectable farther away from seismic ships than from other sources. Although one group of bowheads moved away when a seismic ship approached within 7½ km, most bowheads seemed to behave normally when exposed to noise pulses from more distant seismic vessels (Richardson *et al.*, 1986). Also, many bowheads were seen in areas where there had been seismic work in previous years (Figs. 4, 5). Our data suggest that seismic exploration has not caused large-scale abandonment of parts of the summer range. However, little is known about year-to-year recurrence of specific individual whales. We do not know whether individuals return to locations where they were exposed to seismic noise the previous year.

*Main Industrial Area:* In 1980, many bowheads were near a construction site in the centre of the MIA (Figs. 4A, 5A); some whales were exposed to dredge and boat noise (Richardson *et al.*, 1985b). In late August 1980, the large concentration of whales off the Tuk Peninsula also overlapped with the MIA (Fig. 5A). In 1981, most bowheads remained north or west of the MIA. The one concentration in the MIA in 1981 was usually ≥10 km west of the artificial island and drill ship in the Issungnak area. However, some of these whales were exposed to drill ship, boat and probably helicopter noise (Richardson *et al.*, 1985b). In 1982-84, there were considerably fewer whales in the MIA,

particularly near its centre (Figs. 4, 5). In 1982, there was very little overlap between whale distribution and the MIA at any time. In 1983-84, no whales were seen in the MIA in early August, and the low numbers of whales in the MIA during late August were near its edges.

Thus, utilization of the MIA decreased markedly from 1980 to 1982 and then increased slightly from 1982 to 1983-84. There has been no recurrence of the very large numbers seen in the centre of the MIA in 1980, or even of the lesser numbers seen there in 1981.

Oil exploration off the Mackenzie Delta became intensive in 1976. Limited data suggest that many bowheads were in the central MIA in early August 1976-77 but not in 1978-79 (Table 2). The presence of many whales in 1980, after a period of apparent scarcity in 1978-79, casts doubt on the suggestion that there is a trend for decreasing utilization of the MIA. However, bowheads were apparently abundant in the central MIA in 3 of 5 years from 1976 to 1980 but in 0 of 4 subsequent years. The intensity of offshore industrial activities increased gradually from 1976 to 1983-84, and it can be hypothesized that industry began to affect bowhead distribution after 1980.

#### *Natural Factors Affecting Bowhead Distribution*

Year-to-year changes in bowhead abundance occurred outside as well as within the MIA. Industrial activity cannot account for all changes outside the MIA. If distribution outside the MIA varies because of natural factors, reduced use of the MIA might be the result of similar natural factors.

The main activity of bowheads in summer is feeding (Würsig *et al.*, 1985). To obtain sufficient energy, bowheads must feed primarily in areas of above-average plankton abundance (Brodie, 1981b; D.H. Thomson, LGL, pers. comm. 1986). Copepods, one of the main foods of bowheads (Lowry and Frost, 1984), are more abundant in areas with bowheads than in nearby areas without bowheads (Griffiths and Buchanan, 1982; M.S.W. Bradstreet, LGL, pers. comm. 1986). Factors affecting copepods and other zooplankton probably influence bowhead distribution. Distributions of some other baleen whales are affected by changes in their food supplies (Nemoto, 1959; Whitehead and Carscadden, 1985).

Factors affecting zooplankton abundance in the Beaufort Sea are now being studied. It is not yet known whether local abundances of zooplankton and bowheads are correlated, but locations of high zooplankton biomass probably vary. For example, wind direction affects the occurrence of upwelling off the Yukon coast and the position of the estuarine front off the Mackenzie Delta (Herlinveaux and de Lange Boom, 1975; MacNeill and Garrett, 1975; Borstad, 1985; Thomson *et al.*, 1986). Upwellings and fronts affect plankton biomass in other seas, and presumably do so in the Beaufort.

Thus, changes in areas of peak food availability may account for some within- and between-year changes in bowhead distribution. This idea has been formulated as an alternative hypothesis to account for the reduced whale numbers in the MIA (LGL *et al.*, 1984; Thomson *et al.*, 1986). However, the "food hypothesis" would require that there were year-to-year changes in food availability within the MIA in 1980-84, which has not been demonstrated.

#### CONCLUSIONS

Surveys in 1980-84, and limited data from 1976-79, showed

pronounced year-to-year changes in summer distribution of bowheads. There was no evidence that bowheads avoid areas of seismic exploration. However, after 1980 fewer bowheads entered the main area of drilling, dredging and support activities, particularly its central zone. One hypothesis is that cumulative effects of industry have led to avoidance. Another hypothesis is that bowhead distribution varied in response to expected (but unproven) year-to-year changes in food supply. Both factors may be involved.

Continued bowhead surveys and studies of zooplankton dynamics are needed to resolve this question. If many bowheads return to the centre of the industrial area in a year with much industrial activity, this will constitute strong evidence that oil exploration has not excluded bowheads from part of their range. Conversely, if a distribution similar to that in 1980 does not recur, or does not recur until a year when industrial activity is reduced, evidence of displacement will be strengthened. Data on zooplankton biomass in the industrial area will be needed to interpret whether future trends can be accounted for by natural phenomena.

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