Ecological Research Associates

IMPORTANCE OF THE EASTERN ALASKAN BEAUFORT SEA TO FEEDING BOWHEADS: PRELIMINARY REPORT ON 1985 FIELD STUDIES

by

LGL Ecological Research Associates, Inc.
1410 Cavitt St., Bryan TX 77801

G.A. Borstad Associates, Ltd.
10474 Resthaven Dr., Sidney, B.C. V8L 3H7

and

BioSonics, Inc.
4520 Union Bay Place NE, Seattle WA 98105

for

U.S. Minerals Management Service
12203 Sunrise Valley Dr., Reston VA 22091

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Contract no. 14-12-0001-30233.

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PROJECT ORGANIZATION AND ACKNOWLEDGMENTS

This report is a preliminary account of field work conducted by LGL, Bio Sonics Inc. , and G.A. Borstad Associates Ltd. during September and early October of 1985. Results of this study are still being compiled and analyzed at the time of writing (late October), and will be contained in an annual report to be submitted to MMS in early 1986. Thus, data and interpretations given in this preliminary report are tentative and subject to amendment when analysis is completed.

The present report was prepared by W.B. Griffiths, W.J. Richardson, G. Silber and D.H. Thomson of LGL Ltd.; B. Würsig of Moss Landing Marine Laboratories; and G.A. Borstad and D. Truax of G.A. Borstad Associates Ltd.; with assistance from G. Johnson of BioSonics Inc. Other personnel who participated in the fieldwork were J. Goodyear, L. Martin and G. Miller, all of LGL. The authors are also grateful to pilots D. Paulson and B. Radcliff of Empire Airways, and to skipper B. Kopplin of the 'Annika Marie'.

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INTRODUCTION*

Most individuals of the Western Arctic (=Bering Sea) population of bowhead whales spend the period from May or June to September or October in the Beaufort Sea. During this period they apparently consume most of the food needed for the entire year. Bowheads, like other baleen whales, are believed to consume little food in winter, although this point is not conclusively proven in the case of bowheads (Lowry and Frost 1984). In any case, the Beaufort Sea is clearly of critical importance in the annual energy budget of the great majority of the Western Arctic bowheads.

Importance of the Eastern Alaskan beaufort Sea

Most bowheads spend much of the summer in Canadian parts of the Beaufort Sea (Richardson et al. 1985a). However, in some years some bowheads do occur in the eastern part of the Alaskan Beaufort Sea for much of the summer. It is possible that some never travel east into the Canadian Beaufort in certain years (Ljungblad et al. 1983). Parts of the Alaskan Beaufort may be of great importance as a feeding area for these individual whales.

In addition, the eastern part of the Alaskan Beaufort is apparently the western edge of the main summer feeding range (Fig. 1, inset). In some years, considerable numbers of feeding bowheads occur as far west as the easternmost portion of the Alaskan Beaufort Sea. This is particularly true in September, when many bowheads have begun a gradual westward movement (Ljungblad et al. 1984; Richardson et al. 1985a), but are still feeding much of the time. Stomachs of bowheads harvested in autumn at Kaktovik, a community bordering the eastern Beaufort Sea, cent ain zooplankton, mainly copepods and euphausiids (Lowry and Frost 1984). Some feeding has been observed farther west, but the frequency of feeding seems to decrease as bowheads move westward through the Alaskan Beaufort Sea during autumn (Ljungblad et al. 1984, in press.).

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* By W. John Richardson, LGL Ltd.

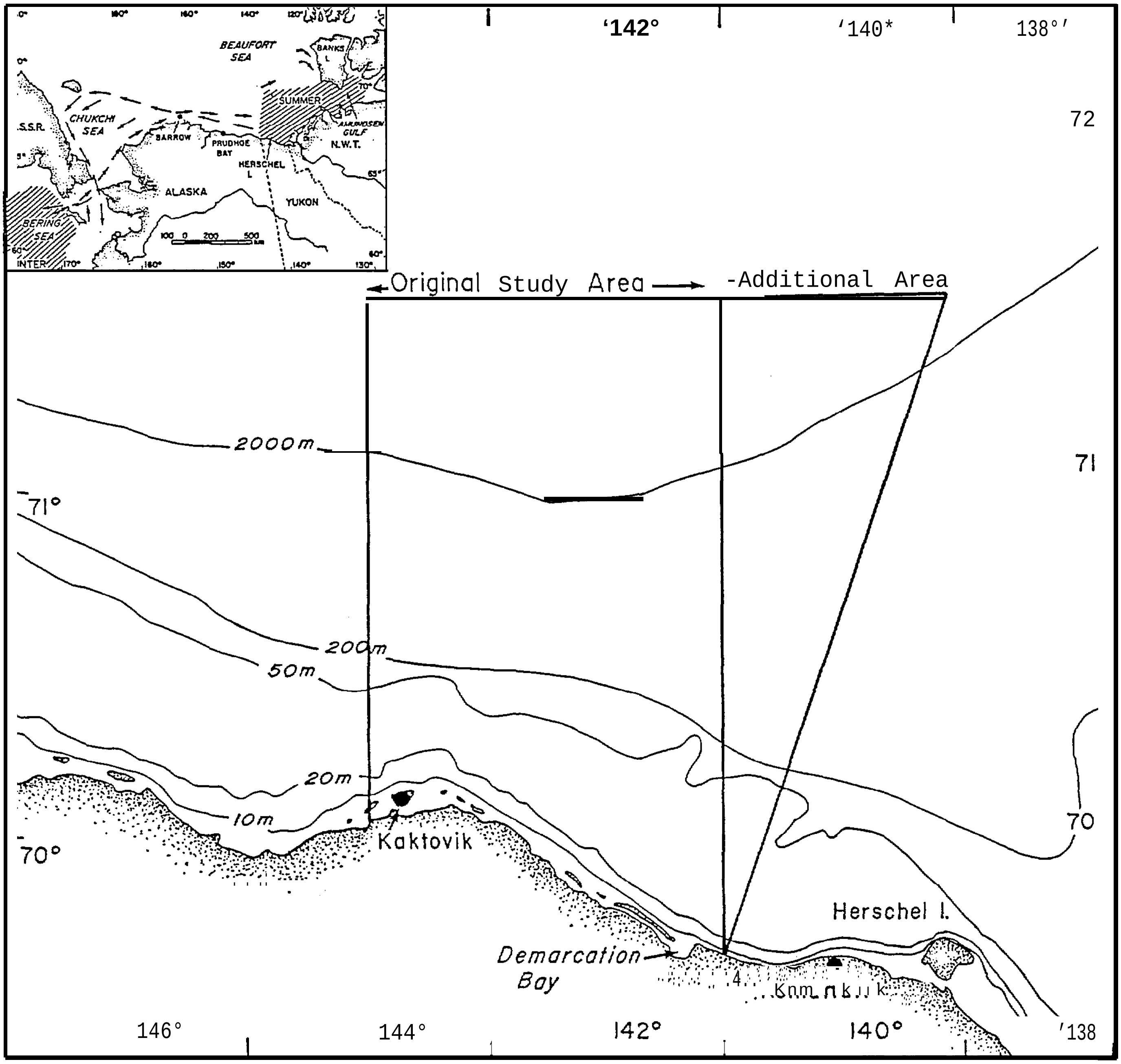


Figure 1. Study area and depth strata for the project, as defined in the original Request for Proposals and as extended based on the MMS request of 2 May 1985. Inset: Generalized pattern of seasonal movement of the Western Arctic population of bowhead whales.

Feeding in late summer and autumn may be especially important to bowheads. This may be the last major feeding period for several months. Also, the energy content of zooplankton is especially high in late summer (Lee 1975; Percy and Fife 1981).

Government agencies that regulate offshore exploration for oil and gas are required to assess whether that exploration has the potential to harm endangered marine mammals such as the bowhead whale. The U.S. National Marine Fisheries Service and the U.S. Minerals Management Service (MMS) have concluded that available information is not adequate to allow a detailed assessment of the possible effects of offshore industrial activities on bowheads that feed in the Alaskan Beaufort Sea.

As a result of this information need, MMS has planned a two-year field study of the importance of the eastern portion of the Alaskan Beaufort Sea (Fig. 1) to feeding bowhead whales. That area was chosen because feeding seems to be more frequent and prolonged there than farther west. A contract for the study was awarded to LGL Ecological Research Associates Inc. in mid-July of 1985. Field work was conducted in September and early October of 1985, and a similar effort is planned in 1986.

Objectives of Overall Project

The general purpose of the two-year project is to quantify what proportion of the energy requirements of the Western Arctic bowhead whale stock is provided by food resources located in the eastern Alaskan Beaufort Sea. To do this, the main factors that must be considered are

- the numbers, activities and residence times of bowhead whales in the area;
- prey identity, availability, distribution, patchiness, and energy content, and oceanographic factors controlling these attributes of the prey;
- amount of prey (and of energy) consumed by the various categories of bowheads that may feed in the study area (immatures, adult males, etc.); and
- total energy needs of individual bowheads and of the population of bowheads.

MMS has itemized the specific objectives of the study as follows:

1. Determine the concentration and distribution of the planktonic food of bowhead whales in the eastern Alaskan Beaufort Sea and correlate with known oceanographic features.

2. Estimate the number of bowhead whales utilizing the eastern Alaskan Beaufort Sea as a feeding area during the summer and fall; observe and document their feeding activities, behavior and residence times.

3. Estimate the degree of utilization of available food resources in the eastern Alaskan Beaufort Sea by the Western Arctic bowhead whale stock.

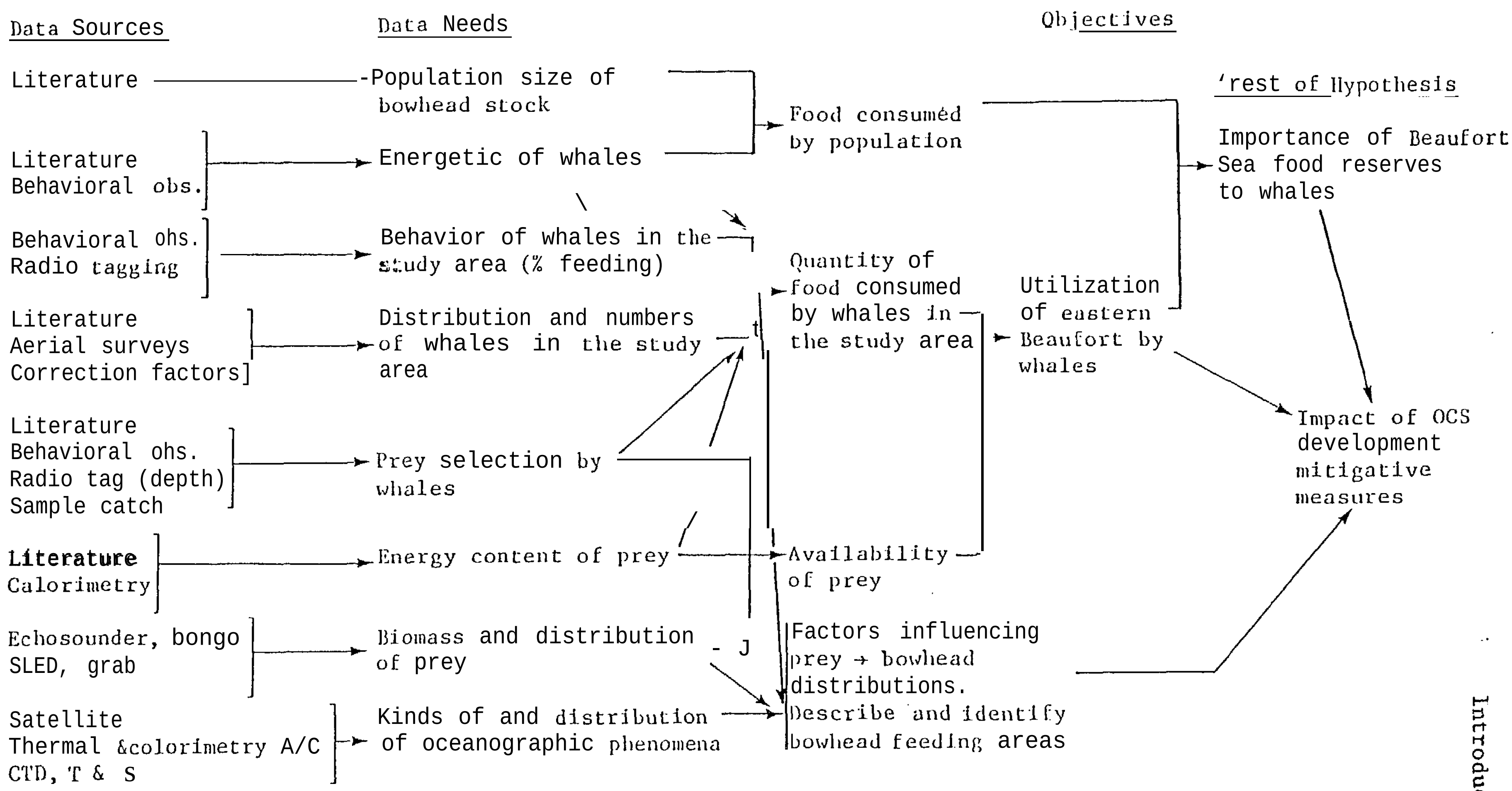
4. Test the following null hypothesis:

Food resources consumed in the Eastern Alaskan Beaufort Sea do not contribute significantly to the annual energy requirements of the Western Arctic bowhead whale stock.

Table 1 is a summary of the various objectives, data needs, and possible data sources involved in addressing the general project purpose. Virtually all study components listed in Table 1 are included in the ongoing research. As shown in Table 1, data available in the literature and from unpublished sources are also being used where possible or necessary (LGL and Arctic Sciences 1985). Literature data will be especially important in addressing questions that require a broader temporal or spatial perspective than can be attained from two seasons of fieldwork within our relatively small study area.

The 1985 and 1986 field programs involve two main tasks: (1) studies of zooplankton and the physical and biological processes that affect zooplankton; and (2) studies of the utilization of the eastern Alaskan Beaufort Sea by bowhead whales. Each of these tasks included a variety of subtasks. Studies of zooplankton and their supporting processes include hydroacoustic surveys to determine zooplankton distribution and relative biomass in various areas; net sampling at selected stations and depths; boat-based measurements of water temperature, salinity, and chlorophyll content; and aerial remote sensing of water temperature, chlorophyll and sediment content on a near-synoptic basis. Satellite imagery is also being used to acquire synoptic data on sea surface temperature and water color on

Table 1. Interrelationships of objectives, data needs and data sources.



the few cloud-free days. Studies of bowhead whales include aerial and boat surveys of distribution, numbers, and movements; observations of feeding behavior and other activities; and photogrammetric work to study population composition and recurrence of identifiable individuals in feeding areas. We were also prepared to use radiotelemetry techniques to study recurrence and behavior, but there were no good opportunities for radio tagging within our study area in 1985.

This preliminary report summarizes the progress made during the 1985 field season toward meeting each of the field subtasks. Where possible at the present early date, this document also summarizes some of the results and implications. However, these results are tentative, since compilation and interpretation of 1985 results will not be completed for several weeks. Detailed results from the 1985 field program will be included in the annual report to be completed for MMS by 31 March 1986.

Study Area

The study area for this project was originally defined as extending between longitudes 141°W and 144°W, and from the coast of northeastern Alaska north to latitude 71°30'N (Fig. 1). However, MMS subsequently expanded the study area to include a triangular zone extending northeast to 71°30'N, 139°05'W. This additional area coincides (approximately) with a zone whose jurisdiction is in dispute between the U.S.A. and Canada. For a review of pre-1985 data concerning the utilization of the study area by bowhead whales in late summer and autumn, see LGL and Arctic Sciences (1985).

We planned to conduct most of our work in the southern 2/3 of the study area, i.e. in the nearshore zone (depths 0-200 m) and the shelf break zone (depths 200-2000 m), with emphasis on the former. There were several reasons: (1) Previous sightings of feeding bowhead whales within our study area have all been in the nearshore zone (LGL and Arctic Sciences 1985; Ljungblad et al. in press). (2) Ice cover and other logistical problems for boat operations were expected to increase with increasing distance from shore. (3) Offshore oil exploration in the study area will begin in shallow waters on the continental shelf. However, the Naval Ocean Systems Center (NOSC), under contract to MMS, agreed to conduct occasional aerial surveys north of the 2000 m contour, and to provide the data for our use. If NOSC detected bowheads far offshore, we were prepared to initiate aerial work there. In actuality, NOSC did not detect bowheads far offshore, and we did not work north of the 2000 m contour. Indeed, few whales were found in any part of our study area during much of September. Consequently some of our aerial work was slightly east of the 'official' study area, at locations near Komakuk where bowheads were present and feeding.

Field Season

Choice of the field period for this project involved a number of unpredictable factors and trade-offs. The duration of the 1985 field program had to be limited to about 25 d of boat-based work and 27 d of aircraft work for budgetary reasons. It was recognized that, during some years, bowhead whales occur in the study area from early August to mid October. however, even in years when some whales are present in August, peak utilization does not occur until mid September (Ljungblad et al. 1984, 1985; LGL and Arctic Sciences 1985). A further factor that affected scheduling was the expected occurrence of ice, which would limit or prevent boat-based work. Despite the fact that bowheads usually do not enter the study area in large numbers until mid September, it was considered ill-advised to commence a 25-d boat program later than 1 September, given that freeze-up often begins in late September.

Consequently, the field season for this project was scheduled to extend from 1 September to 25 September (for the boat) and to 27 September (for the aircraft). In fact, boat work ended on 20 September after ice moved into most of the study area. After discussions with MMS, it was decided to extend the aircraft work until 3 October.

Additional data on utilization of the study area by bowhead whales in 1985 came from other aircraft conducting whale surveys. NOSC conducted surveys in our study area intermittently from August to October. Other LGL projects provided survey coverage near the western edge of the study area from early September to mid October, with occasional coverage within the MMS study area in October. Detailed results from these other projects are not included in this preliminary report, but their sightings are taken into account in our preliminary description of utilization of the study area by bowheads in 1985.

Boat Logistics

The boat crew began to move equipment onto the chartered 13-m vessel, the 'Annika Marie', at Prudhoe Bay on 31 August. Installation was completed on 1 Sept, and the equipment was tested off Prudhoe Bay on 2 Sept. The vessel travelled about 190 km eastward to the study area on 3 Sept, and commenced zooplankton and hydroacoustic sampling on 4 Sept. Broad-scale sampling was conducted along three onshore-offshore transects between Barter Island and Demarcation Bay from 4 to 18 Sept. Work was interrupted by bad weather on Y and 15–17 September, and by engine failure on 11-13 Sept.

Very few bowhead whales were in the study area during this ice free period. Consequently, almost all of the boat time was devoted to broad scale zooplankton and hydroacoustic surveys, along with associated physical measurements. In the absence of concentrations of feeding whales, it was not possible to conduct fine-scale zooplankton sampling operations around feeding bowheads, or to radio tag bowheads.

The storm of 15-17 September brought heavy ice into most of the study area. After the storm, new ice began to form in the narrow nearshore lead through which the vessel had to return westward to Prudhoe Bay. On 19-20 September, the vessel returned to Prudhoe Bay because of the threatening ice conditions. One radio tagging attempt was made while the vessel was in transit westward on 19 Sept. Ice conditions in the study area deteriorated from bad to worse after 20 September. Hindsight confirmed that the vessel departed from the study area at the appropriate time.

Aircraft Logistics

A Twin Otter aircraft (DHC-6-300) on full-time charter for the project was based at Barter Island from 4 September to 3 October 1985. Because whales had moved into the study area in late September after the boat had been forced to cease work, MMS requested that aircraft work continue after the originally-scheduled cut-off date (27 Sept) into early October. The aircraft used for the project was equipped with bubble windows to facilitate observations, a GNS 500A Very Low Frequency navigation system, a ventral camera port for vertical photography of whales, and antennae and receivers for monitoring sonobuoys and radio tags.

One or more flights were made on every day when weather allowed. We made a total of 26 offshore flights, plus several additional flights to calibrate equipment and reposition the aircraft. Total flight hours out of Barter Island were 99.4. Our aircraft work, as well as that of other groups, was sometimes curtailed by bad weather. Nonetheless, all planned types of aircraft-based work (aside from monitoring of radio-tagged bowheads) was conducted successfully. The decision to base the aircraft adjacent to the study area at Barter Island, rather than at Prudhoe Bay, proved to be a good choice. We were sometimes able to fly when aircraft based at Prudhoe Bay were grounded by bad weather. The minimal ferry time from Barter Island to the study area was also a great advantage.

ZOOPLANKTON AND HYDROACOUSTICS*

Introduction

Zooplankton comprise the primary food utilized by bowhead whales that feed in the study area. Stomachs of bowheads taken there during autumn contain mainly copepods and euphausiids, with only small quantities of other organisms (Lowry and Frost 1984). Some surveys of the species and abundances of various zooplankton groups in the study area have been done (e.g. Homer 1979). However, virtually no data are available on the biomass of zooplankton within our study area (LGL and Arctic Sciences 1985). Also, there have been no previous studies of the variability or 'patchiness' in distribution of zooplankton in the study area, or of the physical factors that are assumed to affect zooplankton abundance. Indeed, before 1985 there had been very little

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* By W.B. Griffiths and D.H. Thomson, LGL Ltd.

direct investigation of these topics anywhere in the Beaufort Sea. These matters are all important in evaluating the importance of the study area to bowhead whales.

The objectives of the 1985 zooplankton program were to determine the broad scale patterns of abundance of zooplankton within the southern portion of the study area, to determine the fine-scale characteristics of the zooplankton near concentrations of feeding whales, and to collect physical and other data that could be used to evaluate the factors controlling zooplankton abundance in the study area. The 1985 field season was planned around a 25-d charter of a 13-m boat, the 'Annika Marie'. The intent was to conduct a broad scale survey of zooplankton in the southern part of the study area early in the field period (probably before the arrival of many whales), and then to conduct fine-scale surveys of zooplankton near concentrations of feeding whales. If time allowed, additional broad-scale surveys were planned at the end of the field season. A combination of quantitative hydroacoustic surveys plus net sampling was planned during both broad- and fine-scale surveys.

It was expected that this approach might have to be modified in response to the unpredictable vagaries of ice, weather, and whale distribution, and that was indeed the case. Ice that had covered the study area until late August moved offshore by early September, so broad-scale surveys of zooplankton began on time. There were virtually no whales within the study area in early and mid September, so fine-scale work near feeding whales was not possible. Ice covered most of the study area after 17 September, and boat-based work within the study area was not possible after 19 September. Thus, the 1985 broad-scale surveys provided much new information about the vertical and horizontal distribution of zooplankton within the eastern Alaskan Beaufort Sea, the patchiness of the zooplankton, and its quantitative composition. Physical measurements from the boat as well as from airborne and satellite sensors were also acquired; these physical data will be useful in analyzing the factors affecting zooplankton abundance. However, it was not possible to study the characteristics of the zooplankton near feeding whales, since concentrations of feeding whales did not occur in the study area until late September, when ice prevented boat-based work. The data that were acquired should allow us to estimate the characteristics of the food available to bowhead whales over a large segment of the study area.

Methods

The stomachs of bowhead whales taken in our study area contained mainly large (>2 mm length) marine zooplankters like the "herbivorous copepod *Calanus hyperboreus* and the euphausiids *Thysanoessa* spp. (Lowry and Frost 1984). These large organisms were selected as the focal points of the present study. To facilitate their capture, we used a large mesh size (0.5 mm) on both nets of the bongo frame that formed the main sampling gear.

Zooplankton is known to occur in patches or bands of variable size (e.g. 10's or 100's of meters). To determine the food available to bowhead whales, it was necessary to estimate both the spatial extent of the patches and the biomass available within and between patches. To accomplish this, we conducted co-ordinated hydroacoustic surveys along transects and net sampling at specific stations along those transects. Hydroacoustic surveys with quantitative high-frequency echosounders provided a way to determine the relative biomass at each depth along various transects, and to reveal the dimensions and locations of patches of concentrated zooplankton. Net sampling provided a way to document the actual biomass of zooplankton at selected locations inside and outside patches, and to obtain data on the species composition, sizes, and caloric content of the zooplankters. One aim is to develop a regression relationship that can be used to convert relative biomass data from hydroacoustic surveys into absolute biomass.

All boat-based sampling was conducted from the 'Annika Marie' in the 4-18 September 1985 period. Locations of sampling stations and of hydroacoustic transects were determined using a Magnavox 4102 satellite navigation system. We completed two SSW-NNE transects from shallow waters out to the 250 m contour (Boat Transects 1 and 2), plus another transect out to the 40 m contour (Boat Transect 4; Fig. 2). Arrival of ice in the study area in mid September prevented further sampling. The following subsections

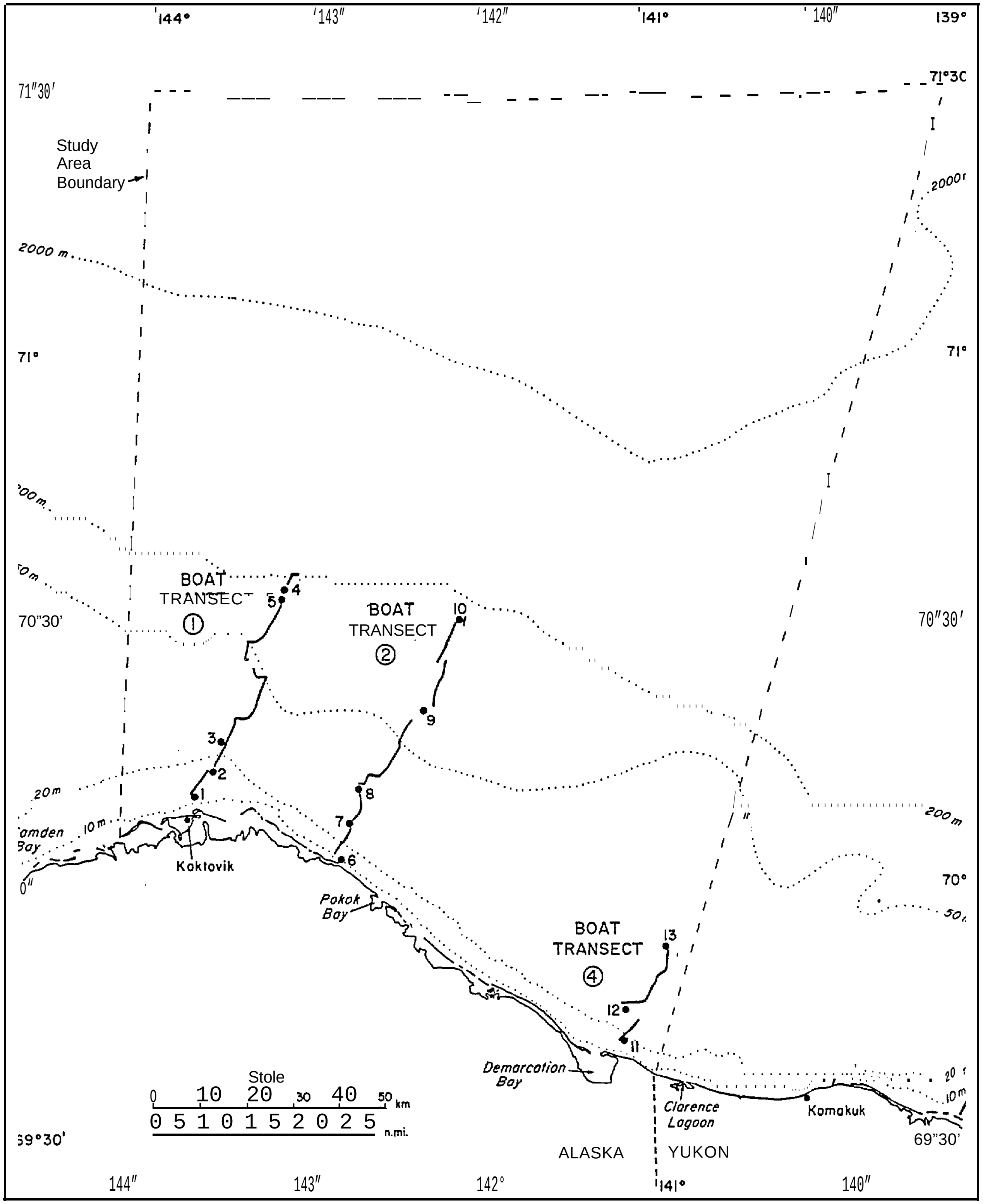

Figure 2. Locations of the three hydroacoustic transects and of 13 stations for zooplankton sampling. Depth contours are from published hydrographic charts, and are approximate. In particular, actual depths at stations 2 and 3 exceeded those implied by the published depth contours (cf. Table 2).

summarize the field methodology. Methods of sample and data analysis will be described in the annual report to be submitted in early 1986.

Sampling at Specific Stations

Net sampling was conducted at 13 stations along the three hydroacoustic transects. Table 2 shows the locations of the 13 sampling stations, and the types of samples collected at each.

Oblique Bongo Tows.--Oblique zooplankton samples were collected using a bongo frame fitted with two 0.61 m diameter plankton nets (mesh size 505 µm) and a flow meter (General Oceanics Inc., model 2030). The nets were towed at approximately 1 m/s and sampled the water column during both descent and ascent. This descent-ascent cycle was repeated three times in depths <15 m and twice in depths 15-20 m in order to obtain a tow of sufficient duration to compare with those from greater depths. One oblique zooplankton sample was collected at each station, ice conditions permitting.

Horizontal Bongo Tows.--Horizontal zooplankton samples were collected using the bongo assembly described above. In addition, an upward looking depth-sounder transducer (Apelco model) was attached to the bongo frame in order to provide precise control of sampling depth. The transducer was hard-wired to a deck unit that provided both a hard copy printout and a digital readout from which the sampling depth could be determined. Tows were made by lowering the net assembly to the desired depth and towing at about 1 m/s for five minutes before retrieval. At least one horizontal plankton sample was collected at each station. In cases where bands of zooplankton were detected by the quantitative echosounder, several tows were made within and between the bands.

Calorimetry and Isotope Sampling.--To determine the caloric content of the major groups of zooplankters (e.g., hyperiid amphipods, euphausiids, large and small copepods, etc.) and to determine their carbon isotope composition in the study area, the samples from one of the two nets of the bongo assembly were placed in whirlpacs and frozen. These samples were sent

Table 2. Summary of samples collected in the eastern Alaskan Beaufort Sea, 4-18 September 1985. CTD = conductivity/temperature profile, S = secchi disc, OB = oblique bongo tow, HB = horizontal bongo tow, TT = Tucker Trawl tow, WS = water sample.

Station	Sample Type	Sample Depth (m)	Water Depth (m)	Date	Time* (ADT)	Location **	
Transect 1							
Station 1	CTD	11.0	13.0	04/09/85	1000	70 °09'N	143°37'W
	OB	10.0		04/09/85	1112	70″10’N	143°35'W
	HB	10.0		04/09/85	1519	70°09'N	143°34'W
	HB	1.0		04/09/85	1600	70″10’N	143°33'W
	TT	8.0		04/09/85	1703	70°10'N	143°35'W
Station 2	CTD	25.0	28,0	05/09/85	2024	70°13'N	143°29'W
	OB	25.0		05/09/85	1041	70°13'N	143°29'W
	HB	14.0		05/09/85	1105	70°13'N	143°29'W
Station 3	CTD	22.0	45.0	05/09/85	1947	70°16'N	143°25'W
	OB	35.0		05/09/85	1422	70°16'N	143°26'W
	HB	25.0		05/09/85	1232	70°17'N	143°24'W
	HB	22.0		05/09/85	1302	70°17'N	143°24'W
	HB	8.0		05/09/85	1330	70°17'N	143°26'W
	HB	15.0		05/09/85	1348	70°16'N	143°26'W
	HB	0.5		05/09/85	1408	70°16'N	143°26'W
	TT	8.0		05/09/85	1448	70°16'N	143°26'W
Station 4	CTD	122.0	125.0	06/09/85	1208	70°34'N	143°07'W
	OB	80.0		06/09/85	1229	70°34'N	143°06'W
	HB	5.0		06/09/85	1255	70°34'N	143°05'W
	HB	30.0		06/09/85	1314	70°35'N	143°04'W
Station 5	CTD	75.0	80.0	06/09/85	1749	70°33'N	143°06'W
	OB	50.0		06/09/85	1655	70°33'N	143°06'W
	HB	55.0		06/09/85	1634	70 °33'N	143°05'W
	HB	5.0		06/09/85	1617	70°33'N	143°06'W
	TT	40.0		06/09/85	1724	70°33'N	143°05'W
Transect 2							
Station 6	CTD	9.0	10.0	09/09/85	1836	70 °03'N	142°45'W
	WS	9.0		09/09/85	1840	70°03'N	142°45'W
	S	4.0		09/09/85	1834	70°03'N	142°45'W
	ice cover too extensive to permit zooplankton tows						

* Time is Alaska daylight time and is the start time of each tow
** positions given are those at the start of each tow.

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Table 2. Continued.

Station	Sample Type	Sample Depth (m)	Water Depth (m)	Date	Time* (ADT)	Location **	
Transect 2 (Cent'd)							
Station 7	CTD	24.0	25.0	07/09/85	1334	70°07'N	142°42'W
	WS	25.0		08/09/85	0918	70°07'N	142°42'W
	S	13.9		07/09/85	1330	70°07'N	142°42'W
	06	22.0		07/09/85	1347	70°07'N	142°43'W
	HB	5.0		07/09/85	1406	70°07'N	142°41'W
	HB	16.0		07/09/85	1423	70°07'N	142°41'W
Station 8	CTD	42.0	42.0	07/09/85	1712	70°11'N	142°39'W
	WS	40.0		08/09/85	1023	70 °11'N	142°39'W
	S	10.5		07/09/85	1710	70 °11'N	142°39'W
	OB	39.0		07/09/85	1635	70°11'N	142°39'W
	HB	18.0		07/09/85	1541	70°12'N	142°38'W
	HB	12.0		07/09/85	1601	70°11'N	142°38'W
	HB	6.0		07/09/85	1617	70°11'1!	142°38'W
	TT	6.0		07/09/85	1654	70°11'N	142°39'W
Station 9	CTD	50.0	56.0	08/09/85	1325	70°20'N	142°19'W
	WS	50.0		08/09/85	1418	70°20'N	142°19'W
	S	8.8		08/09/85	1322	70°20'N	142°19'W
	OB	50.0		08/09/85	1440	70°20'N	142°19'W
	HB	19.0		08/09/85	1455	70°20'N	142°17'W
	HB	32.0		08/09/85	1516	70°21'N	142°14'W
	HB	9.0		08/09/85	1536	70°21'N	142°14'W
	TT	7.0		08/09/85	1557	70°21'N	142°13'W
Station 10	CTD	170.0	185.0	10/09/85	1205	70°31'N	142°04'W
	WS	175.0		10/09/85	1237	70°31 'N	142°07'W
	S	8.1		10/09/85	1203	70°31'N	142°04'W
	OB	100.0		10/09/85	1403	70°31'N	142°06'W
	HB	90.0		10/09/85	1441	70°30'N	142°06'W
	HB	18.0		10/09/85	1509	70°30'N	142°05'W
Transect 4							
Station 11	CTD	13.0	14.0	18/09/85	0924	69°42'N	141°09'W
	S	2.7		18/09/85	0920	69°42'N	141°09'W
	OB	10.0		18/09/85	0935	69°42'N	141''10'W
	HB	0.5		18/09/85	0951	69°42'N	141*10'W
	HB	8.0		18/09/85	1007	69°42'N	141°09'W
	HB	10.5		18/09/85	1024	69°42'N	141°09'W
	TT	9.0		18/09/85	1046	69°43'N	141°09'W

* Time is Alaska daylight time and is the start time of each tow
** Positions given are those at the start of each tow.

..0 /cent'd

Table 2. Continued.

Station	Sample Type	Sample Depth (m)	Water Depth (m)	Date	Time* (ADT)	Location **	
Transect 4 (Cent'd)							
Station 12	CTD	23.0	25.0	18/09/85	1323	69°45'N	141°09'W
	S	4.6		18/09/85	1320	69°45'N	141°09'W
	OB	20.0		18/09/85	1309	69°46'N	141°09'W
	HB	12.0		18/09/85	1224	69°46'N	141°07'W
	HB	20.0		18/09/85	1238	69°46'N	141"10'W
	HB	5.0		18/09/85	1254	69°46'N	141°09'W
	TT	11.0		18/09/85	1207	69°44'N	141°05'W
Station 13	CTD	38.0	40.0	18/09/85	1523	69°53'N	140°55'W
	S	8.2		18/09/85	1520	69°53'N	140°55'W
	OB	35.0		18/09/85	1527	69°53'N	140°55'W
	HB	12.0		18/09/85	1542	69°54'N	140°56'W
	HB	30.0		18/09/85	1600	69°54'N	140°56'W
	HB	5.0		18/09/85	1618	69°53'N	140°52'W
	TT	20.0		18/09/85	1638	69°53'N	140°52'W

* Time is Alaska daylight time and is the start time of each tow
** Positions given are those at the start of each tow.

to the University of Alaska for analysis. Results are not yet available, but will be included in the annual report in early 1986.

Tucker Trawl Tows.--To determine if large individuals of specific zooplankton groups (i.e. euphausiids, hyperiid amphipods) were sampled adequately during horizontal bongo tows, eight samples were collected using a modified Tucker Trawl. The trawl consisted of a stainless steel frame (2.0 x 2.0 m) attached to a tapering knotless nylon net (stretched mesh 0.64 cm) dyed black to reduce the amount of reflected light. The trawl was towed by a yoke attached to the tope of the frame. The vertical orientation of the net was maintained by suspending a weight from the bottom of the frame. In this way the net could be towed without a bridle, thus eliminating any pressure wave that might cause larger zooplankters to take avoidance reactions. The trawl was equipped with a flow meter (General Oceanics Inc., model 2030) and was towed horizontally at approximately 1 m/s at the depth where large organisms appeared to be concentrated according to the hydroacoustic echograms.

Temperature and Salinity.--Continuous temperature and salinity profiles (i.e. from surface to bottom) were measured at each station using an Applied Microsystems CTD-12. The data were recorded on a self-contained tape recording unit.

Hydro Casts.--At each of the five stations on Transect 2, water samples for nutrient analyses were collected at 5 m intervals from the surface to a depth of 20 m; at 10 m intervals at depths of 20 to 50 m; and at additional depths of 100, 150 and 175 m at the deepest station. All samples were filtered, preserved with three drops of 2% $HgCl_2$, and stored unfrozen. Chlorophyll samples were collected at each water sampling depth. One liter of water from each station-depth combination was filtered on 47 μm glass fiber filters; the filters were folded in half, placed in glassine envelopes and frozen.

In addition, samples for the analysis of C^{13}/C^{12} isotope ratios were collected at the most offshore station on Transect 2 at depths of 5, 100 and 175 m. These samples will be used to investigate energy flow pathways

(Schell et al. 1984). These samples were preserved with three drops of 2% $HgCl_2$ and were stored unfrozen in glass bottles.

Hydroacoustic Sampling.--Acoustic data were collected during all zooplankton tows at each station. A detailed description of the hydroacoustic system will be provided in the annual report. Briefly, the system was composed of four major elements: (1) BioSonics Model 101 acoustic transceiver operating at either 120 kHz or 200 kHz; (2) BioSonics 120 kHz and 200 kHz transducers mounted in a towed body; (3) a digital VCR recording system; and (4) BioSonics Model 121 Echo Integration System. The results included real-time digital data on relative biomass at different depths, and hard copy echograms from both transducers.

Survey Sampling Between Stations

Table 3 shows locations, depth, temperature and salinity data for the three broad-scale transects within the study area.

Hydroacoustic Surveys.--Hydroacoustic surveys were conducted between the stations along each of the transects using the system described above. The 120 kHz and 200 kHz transducer assembly was towed at approximately 8.3 km/h; real-time echo integration results were recorded continuously and hard copy printouts for each two minute segment were recorded. In addition, echograms from the simultaneously pinging 12(J kHz and 200 kHz transducers were obtained for the entire survey.

Temperature, Salinity and Depth.--During surveys between stations, near-surface temperature (± 0.1°C), conductivity (± 0.1 millimhos/cm) and water depth measurements were taken every 15 minutes. Temperature and conductivity values were obtained with a Hydrolab System 4000 from surface water samples. Conductivity readings were converted to salinity values according to conversion formulae contained in Perkin and Lewis (1980). In addition, 18 salinity samples were collected during the surveys. Depth was determined by direct readout from the hydroacoustic system.

Table 3. Summary of continuous hydroacoustic surveys, surface temperatures and conductivities recorded in the eastern Alaskan Beaufort Sea, 4-18 September 1985. Numbers in parentheses are salinities in ppt.

Transect Number	From Station to Station	Time* (ADT)	Date	Location		Water Depth (m)	Temp (“C)	Conductivity micromho/cm @ 25°C x 1000	
1	Sta. 1 - Sta. 2	0935	05/09/85	70”10’N	143°37'W	10.1	0.4	45.0	(29.1)
		0950				16.0	-0.1	48.2	(31.4)
		1005		70°12'N	143°33'W	18.0	0.2	47.4	(30.8)
		1020		70°13'N	143°31'W	28.0	0.1	46.9	(30.4)
1	Sta. 2 - Sta. 3	1139	05/09/85	70°13'N	143°29'W	30.0	0.8	46.4	(30.1)
		1154		70°14'N	143°27'W	33.0	0.4	46.3	(30.0)
		1209		70°15'N	143°25'W	37.0	0.5	47.2	(30.6)
		1224		70°17'N	143°23'W	45.0	0.8	46.9	(30.4)
1	Sta. 3 - Sta. 5	1526	05/09/85	70°17'N	143°23'W	45.0	1.1	46.7	(30.3)
		1541		70°18'N	143°22'W	45.0	0.8	46.5	(30.2)
		1556		70°19'N	143°21'W	42.0	1.4	45.8	(29.7)
		1611		70°19'N	143°17'W	46.0	1.7	43.4	(28.0)
		1626		70°20'N	143°15'N	50.0	1.7	42.6	(27.4)
		1641		70°21'N	143°14'W	51.0	1.7	42.2	(27.1)
		1656		70°22’N	143°13'W	55.0	1.9	41.2	(26.4)
		1711		70°24'N	143°11'W	56.0	2.0	41.2	(26.4)
		1726		70°24'N	143°14'W	48.0	2.2	41.0	(26.3)
		1741		70°25'N	143°16'W	50.0	2.3	40.6	(26.0)
		1009	06/09/85	70°26'N	143°17'W	52.0	1.7	41.7	(26.8)
		1024		70°26'N	143°18'W	52.0	1.6	42.2	(27.1)
		1039		70°28'N	143°17'W	54.0	1.8	40.8	(26.1)
		1054		70°28'N	143°15'W	57.0	2.0	40.5	(25.9)
		1109		70°29'N	143°11'W	57.0	2.2	40.5	(25.9)
		1124		70°30'N	143”10’W	58.0	2.1	39.4	(25.1)
		1139		70°32'N	143°07'W	57.0	2,4	40.2	(25.7)
		1154		70°33'N	143°06'W	80.0	2.4	39.8	(25.4)

* Time (ADT) Alaska daylight time.

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Table 3. Continued.

Transect Number	From Station to Station	Time* (ADT)	Date	Location		Water Depth (m)	Temp (“C)	Conductivity micromho/cm @ 25°C x 1000	
1	Sta. 4 - End of Transect	1334	06/09/85	70°35'N	143°04'W	180.0	2.6	40.1	(25.6)
		1349		70°36'N	143°03'W	235.0	2.6	40.3	(25.8)
		1404		70°36'N	143°01'W	270.0	2.7	39.9	(25.5)
2	Sta. 6 - Sta. 7	1226	07/09/85	70°04'N	142°46'W	12.0	-0.2	48.5	(31.6)
		1241		70°05'N	142°44'W	17.0	-0.4	48.8	(31.8)
		1256		70°06'N	142°42'W	20.0	0.0	48.8	(31.8)
		1311		70°07'N	142°41'W	28.0	0.6	47.7	(31.0)
2	Sta. 7 - Sta. 8	1440	07/09/85	70°07'N	142°42'W	28.0	1.3	48.0	(31.2)
		1455		70°08'N	142°39'W	25.0	1.1	47.5	(30.9)
		1510		70°09'N	142°38'W	38.0	1.0	47.4	(30.8)
		1525		70°11'N	142°39'W	37.0	0.8	47.7	(31.0)
2	Sta. 8 - Sta. 9	1043	08/09/85	70°12'N	142°39'W	40.0	1.5	46.3	(30.0)
		1058		70°12'N	142°37'W	44.0	1.3	46.0	(29.8)
		1115		70°13'N	142°35'W	43.0	1.2	46.8	(30.4)
		1128		70°13'N	142°32'W	43.0	1.2	46.6	(30.2)
		1143		70°14'N	142°29'W	44.0	1.3	46.8	(30.4)
		1158		70°15'N	142°27'W	45.0	1.4	46.7	(30.3)
		1213		70°16'N	142°25'W	49.0	1.6	46.2	(29.9)
		1228		70°17'N	142°25'W	50.0	1.6	45.9	(29.7)
		1243		70°18'N	142°23'W	51.0	1.9	4.4.7	(28.9)
		1258		70°19'N	142°21'W	55.0	2.1	42.8	(27.5)
2	Sta. 9 - Sta. 10	1614	08/09/85	70°21'N	142°13'W	59.0	2.1	43.9	(28.3)
		1629		70°22'N	142°13'W	62.0	1.8	43.5	(28.0)
		1644		70°24'N	142°11'W	62.0	0.9	44.1	(28.5)
		1659		70°25'N	142°10'W	61.0	1.0	42.6	(27.4)

* Time (ADT) Alaska daylight time.

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Table 3. Continued.

Transect Number	From Station to Station	Time* (ADT)	Date	Location		Water Depth (m)	Temp (“C)	Conductivity micromho/cm @ 25°C x 1000	
		1714		70°26'N	142°10'W	58.0	1.1	41.7	(26.8)
		1125	10/09/85	70°26'N	142°12'W	72.0	1.8	40.8	(26.1)
		1140		70°29'N	142°06'W	80.0	1.4	40.6	(26.0)
		1155		70°31'N	142°05'W	163.0	1.6	39.0	(24.9)
2	Sta. 10 - End of Transect	1525	10/09/85	70°30'N	142°03'W	180.0	1.8	38.6	(24.6)
		1530		70°31'N	142°03'W	250.0			
4	Sta. 11 - Sta. 12	1130	18/09/85	69°42'N	141”10’W	14.0	-0.4	45.2	(29.2)
		1145		69°43'N	141°07'W	20.0	-0.4	45.3	(29.3)
		1200		69°44'N	141°04'W	25.0	-0.4	45.1	(29.2)
4	std. 12 - Sta. 13	1330	18/09/85	69°46'N	141°09'W	28.0	-0.3	45.7	(29.6)
		1345		69°46'N	141°07'W	28.0	-0.3	45.1	(29.2)
		1400		69°46'N	141°02'W	29.0	-0.2	44.0	(28.4)
		1415		69°48'N	140°59'W	31.0	-0.2	44.6	(28.8)
		1430		69°49'N	140°58'W	34.0	-0.1	44.2	(28.5)
		1445		69°50'N	140°55'W	36.0	0.0	43.9	(28.3)
		1500		69°52'N	140°54'W	37.0	0.0	44.1	(28.5)
		1515		69°53'N	140°55'W	40.0	0.0	44.0	(28.4)

* Time (ADT) Alaska daylight time.

Chlorophyll.--An aliquot of the surface water sample collected every 15 minutes was read on a fluorometer in order to estimate its chlorophyll content. To calibrate the fluorometer, water samples were obtained by filtering 1 liter of the surface water through glass fiber filters, placing the filters in glassine envelopes, and freezing them for later analysis.

Weather.--During the surveys the following weather information was recorded every 15 minutes: wind speed and direction, barometric pressure and air temperature.

Results

The following material is based on observations made in the field, examination of hard-copy echograms, laboratory analyses of a few plankton samples, and review of a small proportion of the digital data produced by the echo integrator. Only a few plankton samples and very limited quantities of acoustic data have been analyzed at this early date. Hence, the following results are tentative and will be revised in the final report on 1985 work.

Species Composition

The species composition of zooplankton in samples taken at stations 11 and 13 in the southeast corner of the study area (Fig. 2) is shown in Tables 4 and 5. (The copepods have not yet been identified to species; this will be done in the next few weeks.) At both of these stations, copepods and larvaceans were the numerically dominant organisms. In all of the samples, biomass appeared to be dominated by large copepods and macrozooplankters. At stations 11 and 13, important contributors to biomass were copepods, the pteropod *Limacina helicina* and, at certain station/depth combinations, euphausiids, mysids, hyperiid amphipods, and jellyfish. Detailed data on zooplankton composition at all 13 stations will be available for inclusion in the annual report on the 1985 work.

Euphausiids were more abundant in the sample taken at 8 m depth at station 11 (1.64 indiv./m^3) than at any of Homer's (1979) stations in the Alaskan Beaufort Sea (maximum of 0.16 indiv./m^3). The biomass of

Table 4. Density and biomass of zooplankton over a depth of 40 M at station 13 off Demarcation Bay.

SAMPLE NUMBER	50		48		49	
TRANSECT NUMBER	4		4		4	
STATION NUMBER	13		13		13	
TOW DEPTH (M)	5		12		30	
	NO. /M3	MG/M3	NO. /M3	MG/M3	NO. /M3	MG/M3
FISH LARVAE	0.11	4.53	0.08	6.18	0.14	12.37
COPEPODS	0.49	1.68	0.37	2.09	22.75	48.86
LIMACINA HELICINA	0.23	2.73	0.54	10.50	0.08	1.49
PARATHEMISTO LIBELLULA	0.00	0.00	0.21	8.44	0.08	4.71
PARATHEMISTO JUVENILE	0.02	0.06	0.06	0.10	0.21	0.47
HYPERIA GALBA	0.00	0.00	0.02	0.19	0.00	0.00
APHERUSA GLACIALIS	0.02	0.30	0.01	0.05	0.00	0.00
ONISIMUS SP	0.00	0.00	0.01	0.04	0.00	0.00
GAMMARID JUVENILES	0.00	0.00	0.02	0.01	0.00	0.00
MYSIS SP.	0.00	0.00	0.00	0.00	0.00	0.05
CRANGONIDAE LARVAE	0.00	0.00	0.36	7.83	0.17	3.63
DECAPOD LARVAE	0.00	0.00	0.05	0.21	0.00	0.02
THYSANOESSA RASCHII	0.00	0.00	0.00	0.00	0.06	1.46
THYSANOESSA INERMIS	0.00	0.00	0.00	0.00	0.01	0.41
THYSANOESSA INERMIS-A	0.00	0.00	0.00	0.00	0.01	0.75
SAGITTA ELEGANS	0.00	0.00	0.02	0.02	0.21	1.67
EUKROHNIA HAMATA	0.00	0.00	0.01	0.14	0.00	0.00
AEGINOPSIS LAURENTI	0.26	0.45	0.88	0.98	0.80	0.60
AGLANTHA DIGITALE	0.00		0.00	0.00	0.16	1.45
HALITHOLUS CIRRATUS	0.00	0.00	0.02	5.14	0.00	0.82
JELLYFISH UNIDENTIFIED	0.08	3.92	0.00	0.00	0.00	0.00
PLEUROBRANCHIA PILUS	0.01	1.20	0.00	0.00	0.00	0.00
MERTENSIA OVUM	0.01	0.99	0.00	0.00	0.00	0.00
CYDIPPIDA SP.	0.01	0.04	0.00	0.00	0.00	0.00
BOLINOPSIS INFUNDIBULUM	0.00		0.00	0.00	0.00	1.36
OIKOPLEURA VANHOFFENI	7.08	0.50	2.18	0.51	3.78	0.65
LARVACEAN HOUSES	0.00	9.95	0.00	3.84	0.00	5.37
UNIDENTIFIED MATERIAL	0.00	0.48	0.00	0.12	0.00	0.53
TOTAL	8.29	26.83	4.85	46.39	28.47	86.66

Table 5. Density and biomass of zooplankton over a depth of 14 M at station 11 off Demarcation Bay.

SAMPLE NUMBER	38		39		40	
TRANSECT NUMBER	4		4		4	
STATION NUMBER	11		11		11	
TOW DEPTH (M)	.5		8		10.5	
	NO. /M3	MG/M3	NO. /M3	MG/M3	NO. /M3	MG/M3
FISH LARVAE	0.00	0.00	0.03	4.04	0.03	0.01
COPEPODS	4.01	14.39	260.46	208.57	403.82	261.97
LIMACINA HELICINA	0.30	1.06	28.24	7.71	101.77	14.75
PARATHEMISTO LIBELLULA	0.00	0.00	0.64	1.57	0.17	1.04
PARATHEMISTO JUVENILE	0.03	0.09	0.00	0.00	0.00	0.00
HYPERIA GALBA	0.00	0.00	0.00	0.00	0.00	0.00
HYPERIID JUVENILE	0.03	0.03	0.00	0.00	0.00	0.00
APHERUSA GLACIALIS	0.05	0.53	0.13	0.83	0.15	0.79
ONISIMUS NANSENI	0.01	0.08	0.00	0.00	0.01	0.28
ONISIMUS GLACIALIS	0.00	0.00	0.05	0.36	0.01	0.30
ONISIMUS SP.	0.00	0.00	0.00	0.00	0.54	0.34
GAMMARUS WILKITZKII	0.01	0.23	0.01	2.01	0.00	0.00
GAMMARID JUVENILES	0.12	0.03	0.00	0.00	0.01	0.03
CRANGONIDAE LARVAE	0.00	0.00	0.02	0.33	0.00	0.00
DECAPOD LARVAE	0.00	0.00	0.00	0.00	0.00	0.00
THYSANOESSA RASCHII	0.00	0.00	1.56	49.63	0.35	12.43
THYSANOESSA INERMIS	0.00	0.00	0.05	1.59	0.07	2.76
THYSANOESSA INERMIS-A	0.00	0.00	0.03	1.32	0.00	0.00
MYSIS SP.	0.00	0.00	0.19	5.41	3.97	8.68
SAGITTA ELEGANS	0.21	1.19	1.07	6.84	3.87	9.11
SAGITTA MAXIMA	0.12	0.18	0.00	0.00	0.00	0.00
EUKROHNIA HAMATA	0.41	2.52	0.00	0.00	0.00	0.00
AEGINOPSIS LAURENTI	6.75	3.44	2.35	1.70	2.11	1.33
AGLANTHA DIGITALE	0.05	1.86	1.03	8.35	1.51	13.03
HALITHOLUS CIRRATUS	0.02	2.44	0.00	0.00	0.00	0.00
HALITHOLUS PAUPER	0.01	2.48	0.00	0.00	0.00	0.00
HALITHOLUS 8P.	0.05	11.99	0.00	0.00	0.03	2.99
EUMEDUSA BIRULAI	0.00	0.00	0.00	0.00	0.01	0.06
JELLYFISH UNIDENTIFIED	0.00	0.00	0.04	3.64	0.00	0.00
PLEUROBRANCHIA PILUS	0.00	0.00	0.00	0.00	0.00	0.00
MERTENSIA OVUM	0.00	0.00	0.00	0.00	0.00	0.00
CYDIPPIDA SP.	0.08	0.63	0.00	0.00	0.07	0.79
LARVACEANS	7.60	1.00	22.64	4.01	14.31	2.52
LARVACEAN HOUSES	0.00	2.93	0.00	6.17	0.00	10.55
UNIDENTIFIED MATERIAL	0.00	1.15	0.00	0.00	0.00	0.00
TOTAL	19.87	48.24	318.53	314.03	532.84	343.76

euphausiids in this sample was also higher then in any of Griffiths and Buchanan's (1982) samples from the Canadian Beaufort Sea. Our hydroacoustic surveys showed that most of the zooplankton occurred in patches (see below). Many of our samples, including the 8 m sample at station 11, were acquired through use of echosounders to guide the nets to zones of high biomass. Thus, our samples from such areas should be representative of the animals occurring in patches. The data acquired in this way provide the first data on the types and quantities of zooplankton that are available in the specific locations where zooplankton is concentrated.

We also obtained samples by oblique tows through all depths. These oblique samples will give data on average species compositions abundances and biomass. Those data are expected to be more comparable to results reported by previous workers. Plankton samples from our oblique tows have not yet been analyzed.

Patchiness

The distribution of zooplankton was patchy on all scales examined. There were areas of both high and low biomass. For example, biomass was higher in horizontal bongo net samples taken at station 11 than in those taken at station 13 (Tables 4, 5).

Over most of the study area, the zooplankton was concentrated in discrete horizontal layers. At station 13, the zooplankton was concentrated at depths of 10-20 and 30-40 m (Fig. 3). Major contributors to biomass at 12 m depth were the pteropod *Limacina helicina*, the hyperiid amphipod *Parathemisto libellula*, decapod larvae, and fish larvae (Table 4). In the deeper band, the high acoustic scattering was due mainly to copepods and fish larvae (Table 4). The two bands evident on the real-time echograms at station 13 (Fig. 3) were also evident in the quantitative data derived from the echo integrator (Fig. 4). These acoustic backscatter data, when compared to actual biomass in tows and tabulated for all stations, will be used to establish the relationship between acoustic backscatter and actual biomass. From this relationship, we expect to be able to estimate zooplankton biomass at all locations and water depths along the hydroacoustic transects. These data, in

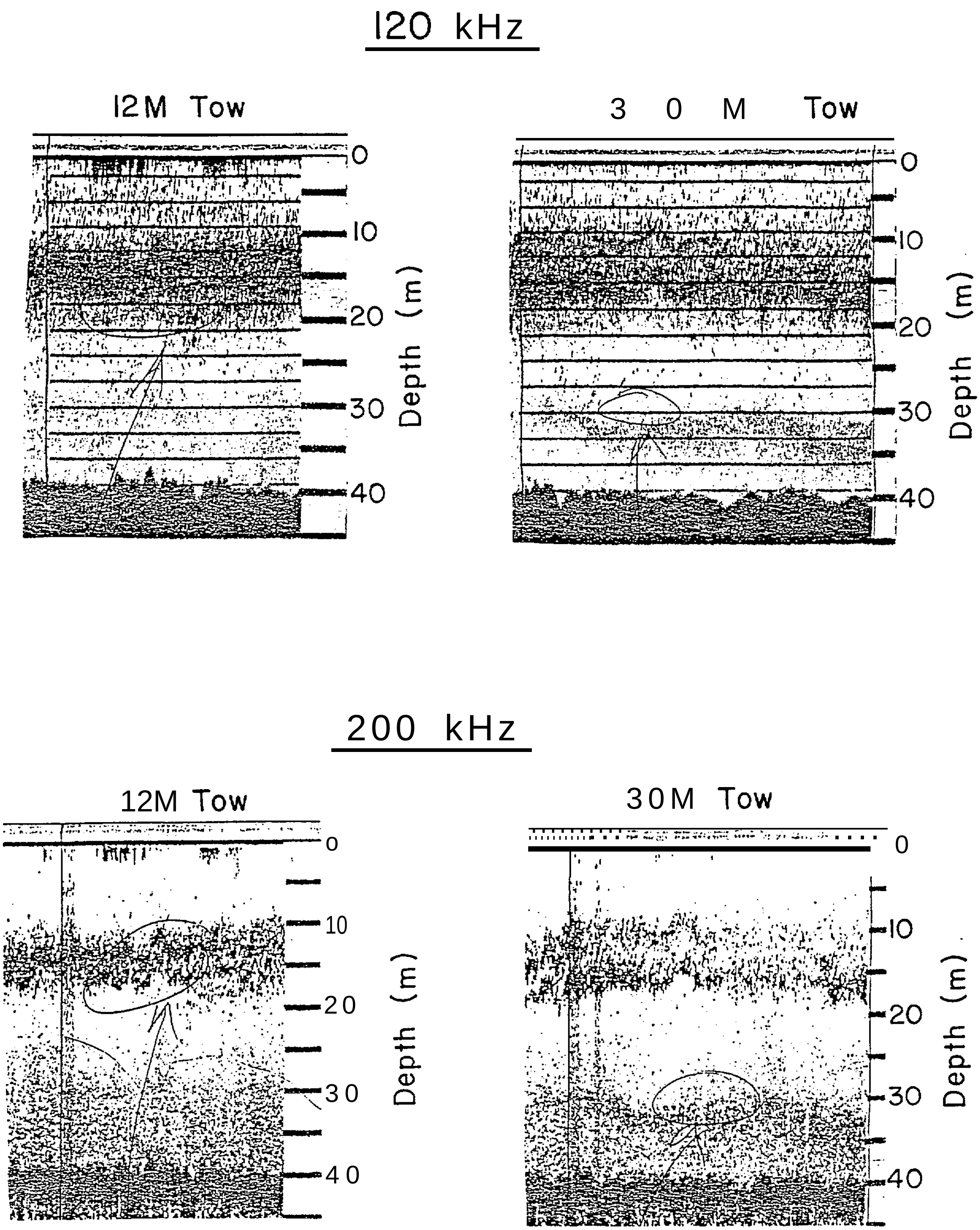

Figure 3. Echograms from 120 kHz and 200 kHz transducers, as recorded during horizontal plankton tows at 12 and 30 m depths at Station 13 on 18 September 1985.

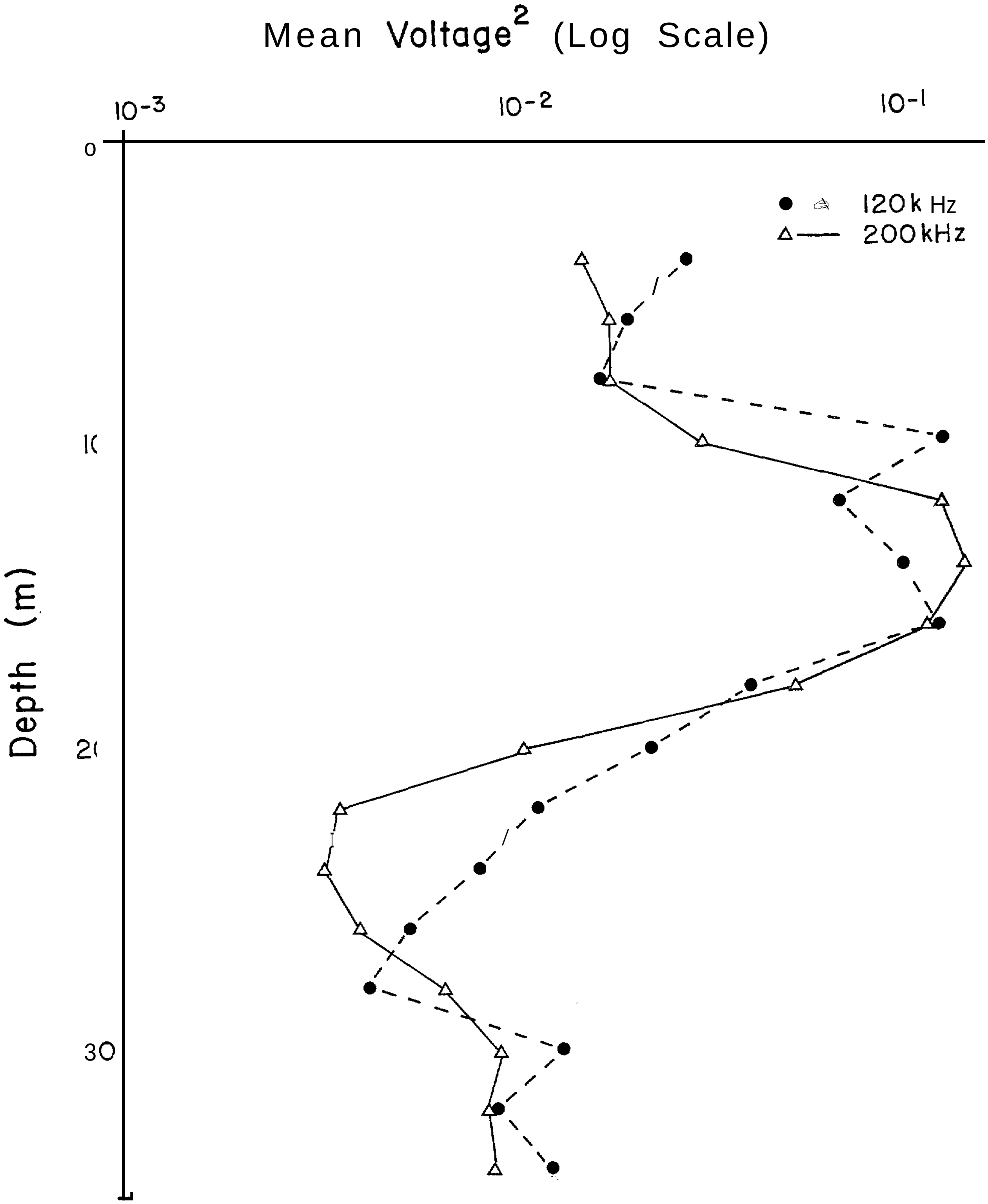

Figure 4. Vertical profiles of 'hydroacoustic biomass' during the 12 m horizontal plankton tow at Station 13. 'Hydroacoustic biomass' is represented by mean output voltage from the echo integrators for the 120 kHz and 200 kHz transducers. Voltage was integrated over the duration of the tow (5 tin) for each 2-m depth range.

turn, will be examined in relation to water mass characteristics and other factors.

At station 13, acoustic backscatter reached a maximum at depths of 10-16 m (Fig. 3, 4). The CTD profile for this station showed that the depth of the pycnocline (zone of sharply increasing salinity and decreasing temperature) was about 11-15 m. Thus, at station 13 there was a close correspondence between the depth of a layer of concentrated plankton and the depth of the pycnocline.

The horizontal distribution of zooplankton was also patchy. Figure 5 shows portions of the echograms recorded as the boat traveled NNE between stations 12 and 13. The 'density' of the band located at 12-15 m depth increased around 14:40, especially on the 200 kHz echogram. During this time, acoustic biomass recorded by the echo integrator increased from 0.04 V to 0.11 V. Variability in the density of the bands was even more dramatic in some other parts of the study area. However, the bands themselves were present in most areas that were sampled. The bands were generally found in midwater as shown in Figure 5. In a few instances, however, zooplankton appeared to be concentrated in a layer just above the sea bottom. In a few cases the bands appeared as actual patches on the echograms. The depth distribution of the bands appeared to be fairly consistent over tens of kilometers, but differed over larger scales.

Biomass

Analysis of zooplankton samples collected during this project has just begun, and few data are available at this early date. The analyses, when completed, will provide the first comprehensive data on zooplankton biomass (and caloric content) in the Alaskan Beaufort Sea. For example, mean biomass in seven horizontal tows from stations 4, 11 and 13 was 149 + s.d. 135 mg/m^3 wet weight. These values are lower than the mean biomasses of 476 and 237 mg/m^3 recorded in the Canadian Beaufort Sea during 1980 and 1981 (Griffiths and Buchanan 1982).

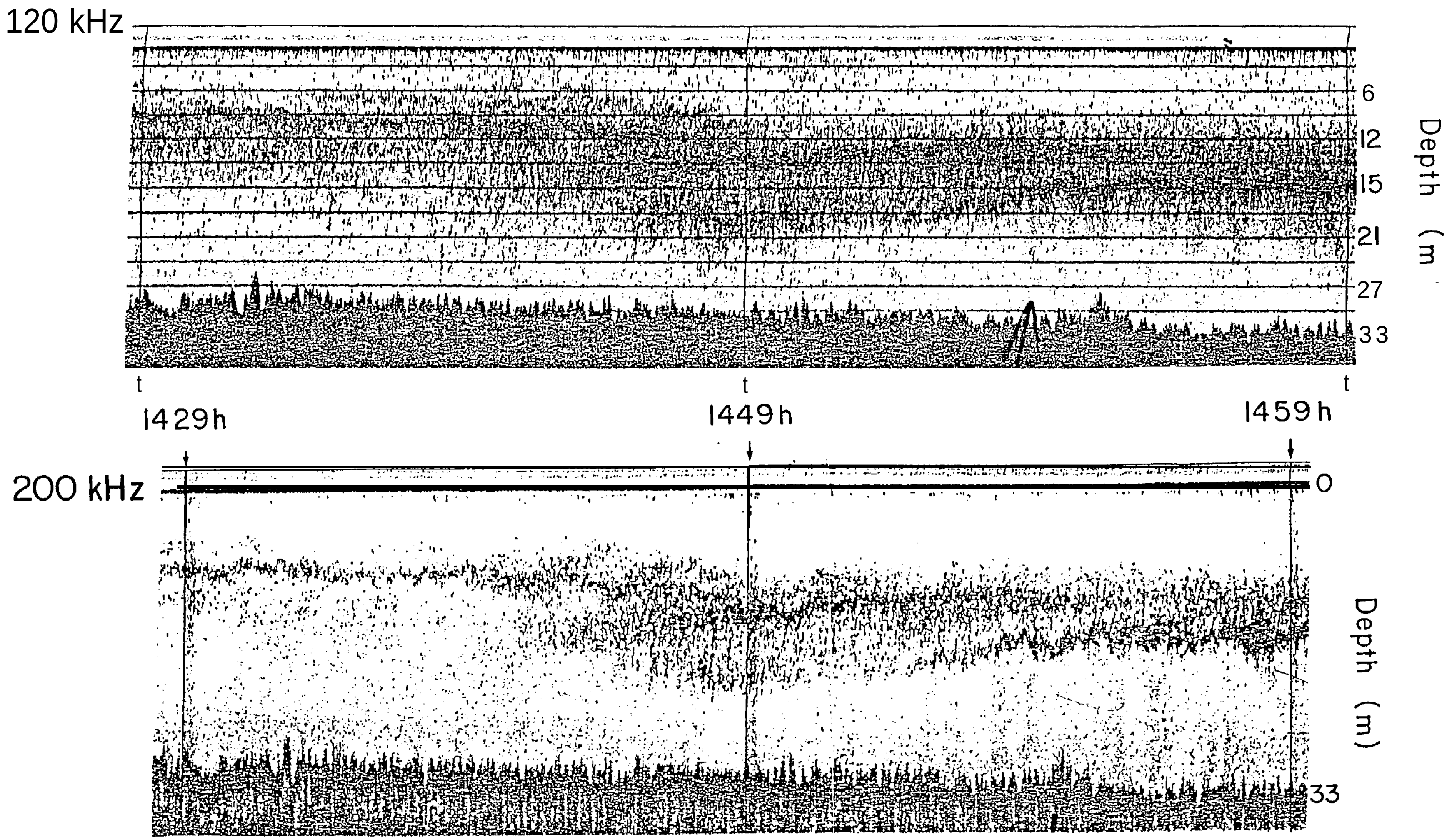

Figure 5. Echograms from 120 kHz and 200 kHz echosounders as recorded along Boat Transect 4 during a survey between Stations 12 and 13 on 18 September 1985. The echograms show concentrations of zooplankton; differences between the two transducers are discussed in the text. The horizontal distance depicted here is about 2.8 km.

A study using similar methods to those used here was conducted by LGL during late August 1985 off the Yukon coast in the Canadian Beaufort Sea. Analysis of samples from the Canadian project has not yet begun. However, cursory examination of samples collected during both studies indicates that, overall, zooplankton biomass was substantially higher in the Canadian Beaufort Sea. There were also notable differences in the nature of the zooplankton collected during the two studies. The samples collected off the Yukon coast were mainly composed of small copepods. The samples collected in the Alaskan Beaufort Sea contained mainly large copepods and other large species such as hyperiid amphipods, euphausiids and pteropods.

Discussion

The distribution of the plankton was extremely patchy on both horizontal and vertical axes. In most parts of the study area, most of the zooplankton biomass appeared to occur within concentrations. However, the biomass contained in these concentrations appeared to be quite variable. Thus, various parts of the study area probably do not provide equally good feeding grounds for bowhead whales. This possibility will be quantified when analyses of the 1985 data are completed.

Because feeding whales were rare in the study area during the period of boat-based observations, we do not know the biomass of zooplankton that would be associated with feeding whales. The aforementioned zooplankton study in the Canadian Beaufort Sea in late August 1985 did include some sampling near feeding bowheads, as did an earlier study (Griffiths and Buchanan 1982). However, the relative composition of the zooplankton was quite different in the Canadian and Alaskan Beaufort Sea in 1985. As a result, the Canadian data may have only limited applicability to our study area.

The species composition of the zooplankton and the sizes of the copepods in our samples appeared to correspond, in a general way, with the kinds and sizes of animals consumed by bowhead whales landed at Kaktovik in earlier years (cf. Lowry and Frost 1984). However, no bowheads were landed at Kaktovik during the autumn of 1985, so there was no opportunity to compare food availability in 1985 with stomach contents of bowheads taken during the same season.

Although sample analysis is incomplete, biomass of zooplankton was apparently higher in an area of the Canadian Beaufort Sea heavily utilized by feeding whales in late August than it was in our study area in early September. Feeding whales were rare in our study area during early-mid September (see 'Bowhead' section, below). In contrast, feeding whales are sometimes present in considerable numbers in at least the eastern part of our study area by mid-September (Ljungblad et al. in press; LGL and Arctic Sciences 1985). One could speculate that the usual westward extension of the feeding grounds into our study area was delayed in 1985 because much food apparently was available in the Canadian Beaufort Sea in late summer, and less was available in the eastern Alaskan Beaufort Sea. However, it is not known whether this pattern of food availability is the usual situation, or whether more food is present in the Eastern Alaskan Beaufort Sea in some other years.

AIRBORNE MEASUREMENTS OF WATER COLOR AND TEMPERATURE*

Introduction

This preliminary report summarizes the airborne water color and temperature observations made by G.A. Borstad and D.N. Truax during the first half of September 1985 as part of the MMS bowhead feeding study. It will be updated when the data analysis is completed and when complementary data from other parts of the project become available.

During the first half of September, the study area north to the 2000 m contour was almost entirely free of ice. During this period, two systematic aerial surveys of the study area were conducted. Continental shelf waters (0-200 m deep) were surveyed on 5-6 September; both shelf and slope waters (0-2000 m deep) were surveyed on 12-13 September. During these aerial

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surveys, water temperature and color were monitored from the aircraft at the same time as observers searched for bowhead whales. In addition to the two systematic surveys, the airborne remote sensing instrumentation was also used during several other flights in early September 1985, including flights along transects surveyed by boat. This allowed cross-calibration of aerial and boat measurements of sea surface temperature, chlorophyll and turbidity.

Background on Remote Sensing Methodology

Sea Surface Temperature Measurements

Remote measurement of surface temperature from either aircraft or satellites involves detection and measurement of thermal infrared radiation in the 8-14 micron region of the electromagnetic spectrum, where absorption by the atmosphere, water vapor, and maritime and stratospheric aerosols is at a minimum. Because of very strong absorption of these wavelengths by liquid water, radiometers viewing a water surface measure the temperature of only a very thin surface 'skin' (top 0.1 mm). Where the sea is very calm and insolation is high, this skin temperature can differ by as much as 1°C from the water temperature a few cm below, where sea surface temperature is usually measured (e.g. , Katsaros 1980). Typically, however, wind-induced turbulence in the upper layers is sufficient that remotely derived sea surface temperatures, after appropriate correction for atmospheric effects, agree with surface 'bucket' temperatures (at about 1 m depth) to within about ± 0.5°C (Tabata and Gower 1980).

Water Color Measurement

The spectral properties of visible radiation emerging from a natural water body are determined by the absorption and backscattering characteristics of the upper layers of the water column, by the character of the incident radiation, and by the transmission properties of the water surface. Since backscattered light is more or less white, the apparent color of the sea (where the depth is great enough that illumination reaching the bottom is absorbed before it returns to the surface) is determined primarily by absorption in water and by dissolved and suspended materials including planktonic algae.

Phytoplankton Chlorophyll Concentration. Since water itself absorbs only weakly at blue wavelengths and maximally in the red, pure water appears blue to an observer. By contrast, phytoplankton pigments have evolved to absorb blue light strongly. Increasing amounts of pigment cause the water color to shift from blue to green. A measure of the ratio of green to blue radiance (G/B) leaving the water relates closely to the phytoplankton chlorophyll concentration in the upper 5 m of the water column (Clarke et al. 1970; Gordon et al. 1983). For this project we have utilized the ratio of 550 nanometer (rim) reflectance to 525 nm reflectance (Fig. 6), since these wavelengths are relatively insensitive to interference by atmospheric path radiance, surface reflection and a number of other potentially interfering factors to be discussed later. However, all indices making use of the blue-green color changes induced by chlorophyll can be affected by dissolved organic materials such as tannins and lignins present in terrestrial runoff, since they, like the plant pigment, also absorb strongly at blue wavelengths. Also, since backscatter effects generally outweigh absorption, low concentrations of suspended inorganic particulate can mask blue-green variations caused by chlorophyll (Morel and Prieur 1977).

A second index of near-surface phytoplankton concentration may be derived from the water color by measuring in vivo fluorescence of chlorophyll a and its phaeopigments. This adds a Gaussian shaped peak near 685 nm to water reflectance spectra (Neville and Gower 1977; Gower 1980; Borstad et al. 1981; Borstad and Gower 1984). Because of greater absorption by water at these longer wavelengths, the height of this fluorescence line (the Fluorescence Line Height or FLH signal) is correlated with the amount of chlorophyll in the uppermost 2 m of the water column. Generally, the factors that interfere with the G/B measure of chlorophyll (surface reflection, atmospheric path radiance, dissolved organic material) do not grossly affect the FLH. However, physiological variability of in vivo fluorescence may affect this index.

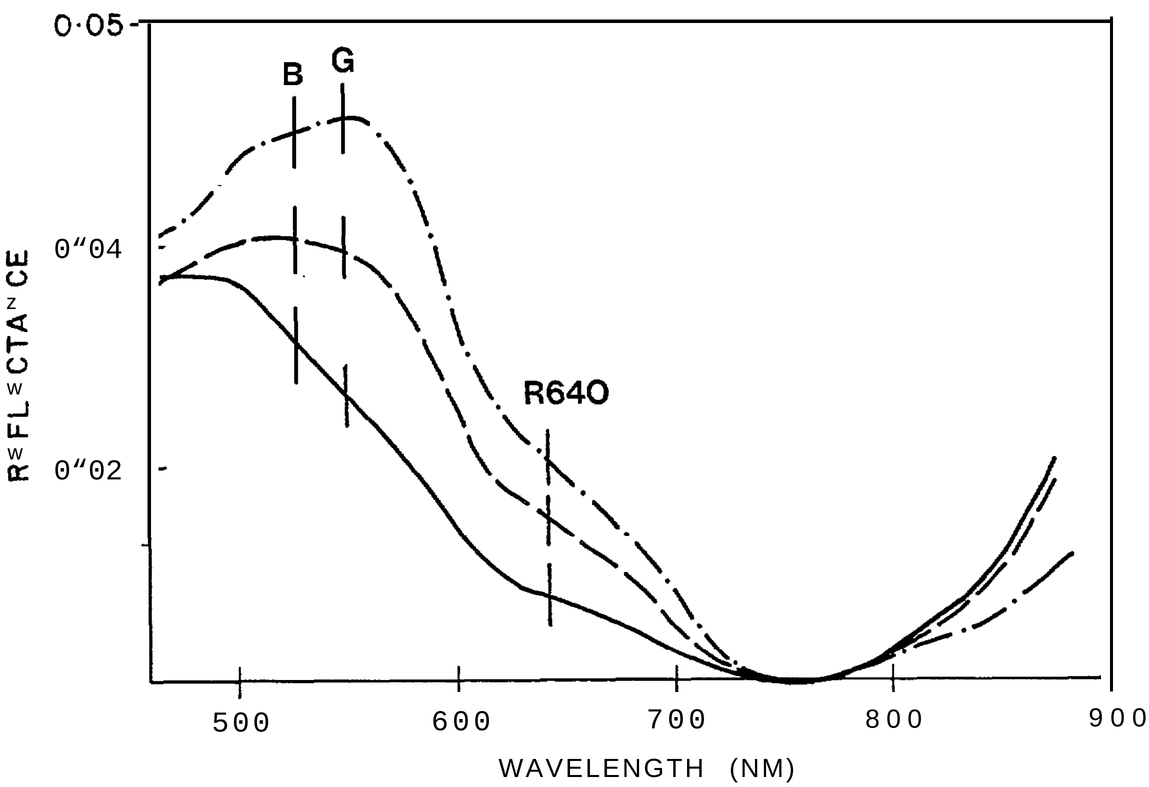


Figure 6. Reflectance spectra measured during the transit northeastward from Pokok Bay, 12 September 1985. The spectra show the effect of increasing suspended inorganic particulate, and the lack of a phytoplankton fluorescence peak at 685 nm. Marks indicate the wavelengths chosen for the R640, G/R, and G/B indices.

Terrigenous Dissolved and Suspended Materials.--Where inorganic particulate material (riverine sediments or glacial flour) is present at concentrations greater than about 1 mg^{-3}, it can dominate the optical processes and alter or mask the G/B and FLH signals from low concentrations of chlorophyll.

It is possible to determine the concentration of suspended inorganic materials indirectly from measures of the upwelling radiance at 550 and 650 nm, where absorption by phytoplankton is at a minimum. Absorption by water is relatively independent of wavelength within this spectral range. We have used both a simple measure of the reflectance at 640 nm (R640) and 550/640 nm ratio (G/R, Fig. 6). Earlier work in the Beaufort Sea has shown that both measures relate closely to total suspended material and also to secchi depth (Borstad 1985). In this preliminary report we show only the R640 distributions.

Instrumentation and Methodology

Survey Procedures

The airborne remote sensing instrumentation was mounted in the Twin Otter aircraft chartered by the project. The equipment was used only during the first half of September, when the study area was almost entirely ice free. Airborne remote sensing had not been planned after mid September because of budgetary limitations. In fact, the arrival of much ice in the study area around 17 September 1985 would have prevented effective remote sensing of water characteristics even if this component of the work had been budgeted to continue later in the field period.

Data on water temperature and color were acquired in three situations:

1. Most of the systematic data were acquired during the first two stratified random surveys to determine the distribution and number of bowhead whales in the study area (see ‘Bowhead Distribution and Activities’ section, later). The standard survey route consisted of 13 transects oriented NNE-SSW from the shore to the 200 m depth contour (average spacing 10.6 km), plus eight N-S transects between the 200 and 2000 m depth contours (average spacing 18.5 km). The first survey was on 5-6 September (nearshore lines only, due to persistent fog); the second was on 12-13 September.

2* On two dates (6 and 11 September), the aircraft flew along Boat Transects 1 and 2 (Fig. 2). The primary purpose was to calibrate the airborne instruments against temperature, chlorophyll and secchi measurements obtained from the boat.

3. On some other occasions while the aircraft searched for whales for purposes of behavioral observations and photogrammetry, the instruments were operated. These 'non-systematic' data are not discussed in this preliminary report.

The aircraft flew at an airspeed of 200 km/h during almost all offshore work. Aircraft altitude was 153 m during the 5-6 September survey, 305 m during the 12–13 September survey, and 153-457 m on other occasions. Observers aboard the aircraft noted sea state, ice conditions, and visible water mass discontinuities. Aircraft position was recorded at frequent intervals from the VLF navigation system.

Airborne Water Color Measurements

Institute of Ocean Sciences Color Spectrometer.--The water color measurements reported here were made with a custom built research spectrometer and techniques developed by and for the Canadian Department of Fisheries and Oceans at the Institute of Ocean Sciences, Sidney, British Columbia, Canada (Neville and Gower 1977; Gower 1980; Borstad et al. 1981; Borstad and Gower 1984; Borstad 1985).

The 10S spectrometer (Walker et al. 1974, 1975) uses a reflection grating and an array of silicon diodes to measure and record the spectral variations of light leaving the sea surface. A custom designed micro-processor acquires, formats and writes spectral data to a 9-track computer compatible tape (Fig. 7). In previous usage of the spectrometer, only one uncalibrated water color index and an oscilloscope trace of the raw spectrum were available in real-time. Digital data on tape were analyzed in the laboratory after return from the field.

For this project, a real-time capability was added to the spectrometer system using an IBM–PC with 640 Kb of RAM memory, and an 8087 co-processor to increase the speed of mathematical operations. A Labmaster Analog-to-Digital interface and appropriate computer programs were used to acquire, display,

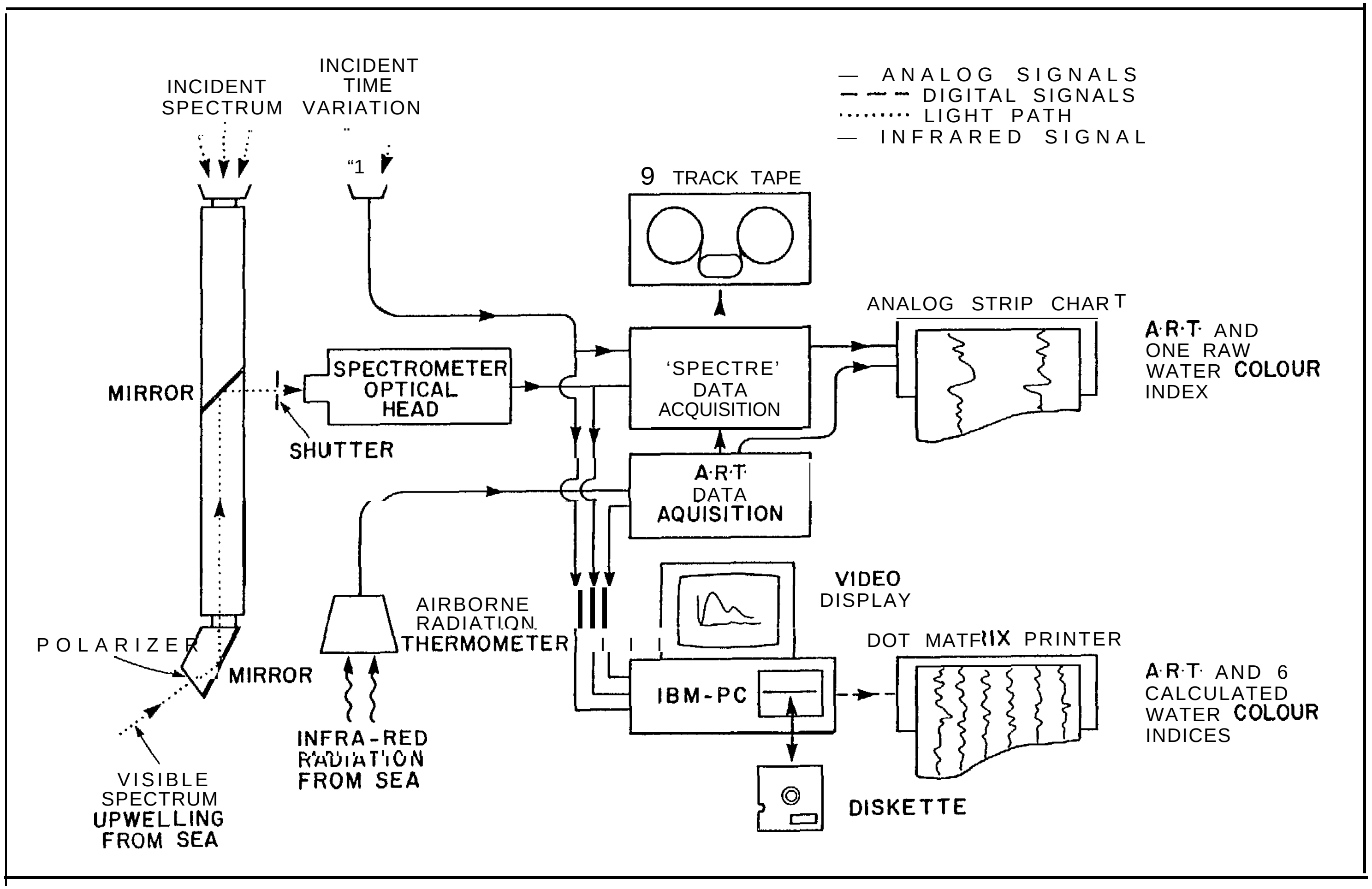


Figure 7. Schematic representation of the IOS remote sensing system used for these surveys.

analyze and store the spectral data. This real-time data acquisition and display system is presently configured as an addition to the original spectrometer system; the 9-track tape now forms the backup for the real-time microcomputer components (Fig. 7).

The real-time analysis of the September 1985 survey data was essentially the same as was previously carried out in the laboratory, except that the operator was able to critically evaluate the data being acquired and correct problems that would otherwise have gone undetected.

Reflectance spectra such as those illustrated in Figure b were computed by normalizing the radiance upwelling from the sea surface (L_u) by the downwelling irradiance (Ed) incident on a horizontal opal glass collector on top of the aircraft fuselage. The reflectance ratio (L_u/E_d) thereby accounted for cloud along the flight path. The spectrum of the incident irradiance was measured frequently when the spectrometer looked up through a hole in the aircraft skin at the opal collector; the intensity of incident irradiance was monitored continuously by a single silicon diode.

Reflectance spectra calculated every 1 to 8 seconds (longer under heavy overcast skies) were corrected for a mean atmospheric scattering contribution appropriate to the aircraft altitude, and for an additive signal from surface reflection, mist and whitecaps. The latter additive signal was assumed to be white. Its magnitude was calculated on the assumption that the corrected reflectance at 780 nm was zero. The continuous computations of the various chlorophyll and turbidity indices, corrected as just described, were plotted against time on strip charts. The data were later transferred to distribution maps, based on the known position of the survey aircraft at frequent time intervals.

The acceptance angle of the spectrometer is small (0.17° x 0.7°) and from 150 m altitude its instantaneous footprint on the sea surface is therefore about 1.4 x 6 m. This is smeared by the forward velocity of the aircraft (about 50 m s^{-1}). Hence, the survey data are for narrow strips between 50 and 200 m long along the flight path, depending on the integration time, aircraft ground speed and altitude.

Further details concerning the measurements and analysis techniques for the airborne data can be found in Gower (1980), Gower and Borstad (1981), Borstad and Gower (1984), and Borstad (1985).

The remote color measurements need to be calibrated using <u>in situ</u> measurements in order to use them quantitatively. Chlorophyll data from the 1985 boat-based sampling are not yet available. However, the FLH index indicated that chlorophyll concentrations were below 0.5 mg m^{-3} everywhere. Hence, the color variations that we observed probably were largely caused by variations in amount of suspended inorganic materials rather than chlorophyll. No measurements of suspended inorganic material were made in this phase of the study; samples should be taken for this variable next year. However, Figure 8 illustrates that there was a close relationship between R640 and secchi transparency for the few stations for which both of these measurements were made. The bar for each station reflects the observed variability along 2 km of the transect in the region of each station.

<u>Airborne Radiation Thermometer (ART)</u>.--The Barnes Precision Radiation Thermometer PRT-5 is a commercial radiometer that measures the 10-12 micron thermal infrared radiation from the ocean using a chopped, temperature stabilized thermistor. The instrument has a 2° field of view, and therefore an instanteous footprint of about 5 m diameter from 150 m altitude. Its precision is about 0.1°C. However, as stated earlier, practical accuracy is about ± 0.5°C.

Laboratory calibration of the ART involves pointing the sensor into a container of stirred water while slowly increasing the water temperature. Since the ART measures the sum of all IR radiation within its field of view, the relationship between the ART output and sea surface temperature can be expected to deviate from the lab calibration because of atmospheric water vapor. This effect is generally a simple linear offset, with no change in slope. When the relative humidity is uniform across the study area, the calibration remains valid.

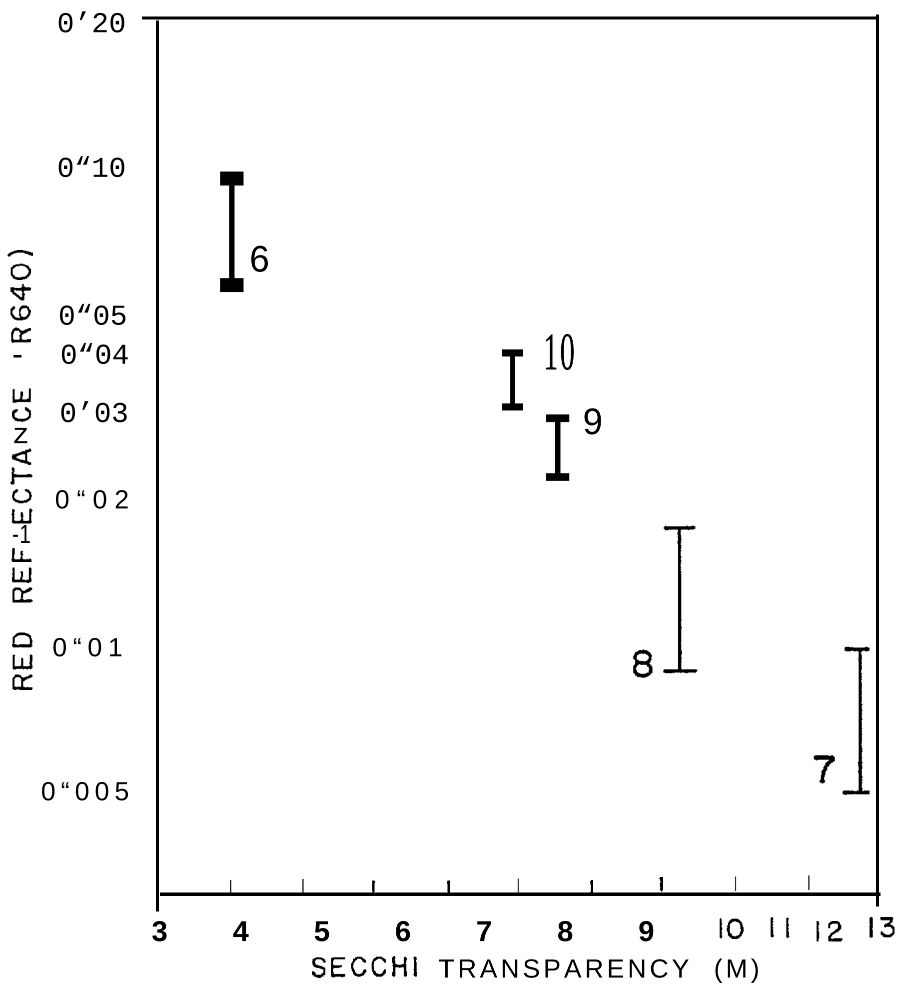


Figure 8. Comparison of airborne observations of the Red Reflectance (R640) Index made on 6 September 1985 with measurements of secchi transparency made at the same locations on 7 to 10 September 1985. Numbers are station numbers along Boat Transect 2 (see Fig. 2).

Comparison of ART data measured on **6** September with in situ sea surface temperatures measured on the 5th and 6th produced the curve in Figure 9. A line with the same slope as the lab calibration fits the 6 September data to within about ± 0.25°C. The fact that the agreement holds for other days (5-8 September) suggests that there was relatively little change in the geographic pattern of temperatures during this period. No ship data on sea surface temperature were available at the time of the 12 and 13 September aerial survey. We have used the calibration data shown in Figure 9 for those days also, although we expect larger errors because of different atmospheric conditions.

Results

Survey on 5-6 September 1985

Sea Surface Temperature.--On 5-6 September we surveyed the nearshore portion of the study area, from shore to the 200 m contour (Fig. 10). On 5 September we surveyed the SE corner of the study area (south of approx. 70°00'N); cloud prevented surveys farther north and west. On 6 September we surveyed the remainder of the nearshore area.

The survey showed a narrow band of water warmer than 0°C immediately along the coast out to about 10 m depth and extending across the full east-west extent of the study area (Fig. 10). This water was visually bright green, and appeared contiguous with warmer and turbid green water in the bays and lagoons.

In water deeper than about 10 m, a band of cold (-0.5 to 0°C) water was present. This cold water formed a band extending 1-10 km from north to south, and extending from east to west across the entire study area. Small scattered bits of ice were observed throughout this cold water, but 1-25% brash ice was present along the thermal gradient separating it from warmer water along the shore. The band of cold water was widest in the center of the study area north of Pokok Bay, and narrowest east of 142°W.

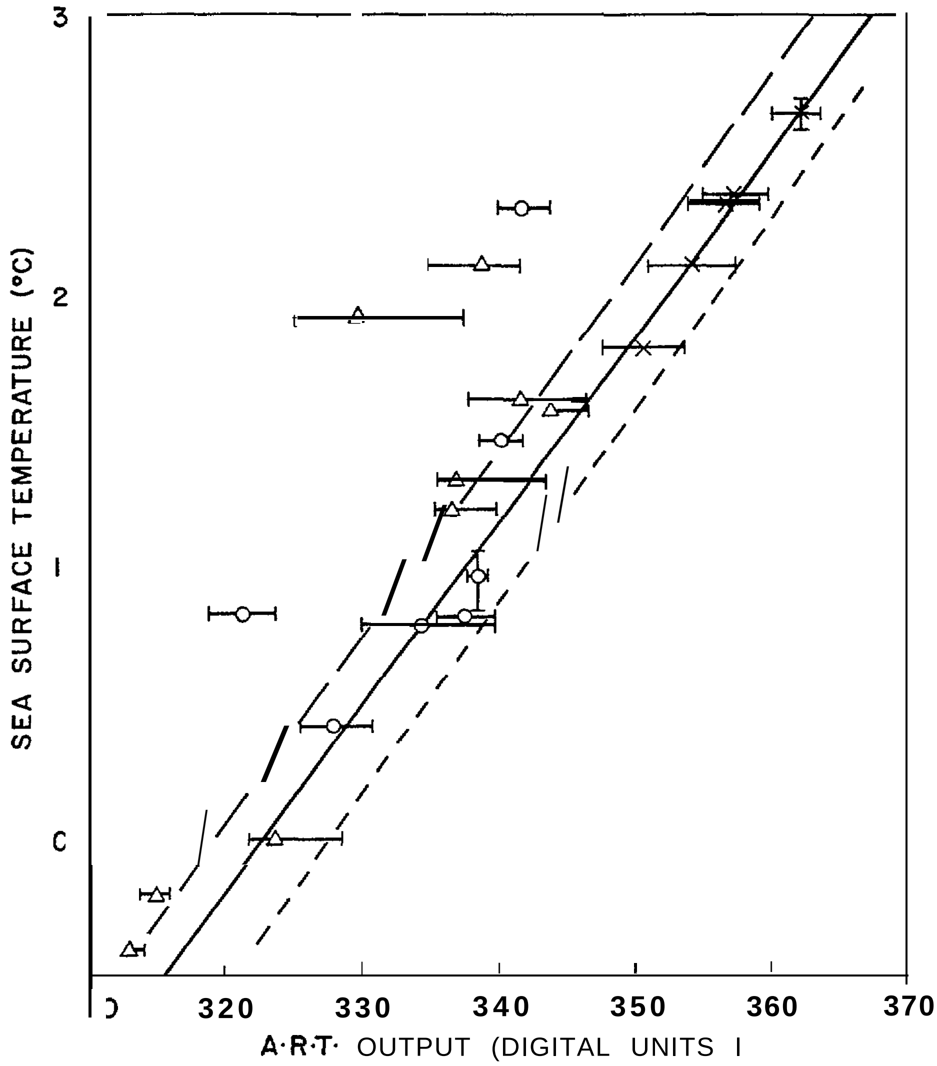


Figure 9. Comparison of Airborne Radiation Thermometer measurements (digital units) made 6 September 1985 from 150 m altitude with in situ sea surface temperatures at the same locations on 5-8 September 1985. The calibration curve (solid line) is drawn parallel to the laboratory calibration but with a vertical offset to take it through the boat-based measurements from 6 September. The horizontal bars indicate the range of ART output for 2 km segments along the flight line, centered on the position of the in situ observations along Boat Transects 1 and 2 (Fig. 2). The dashed lines are ± 1/4°C from the fitted line.

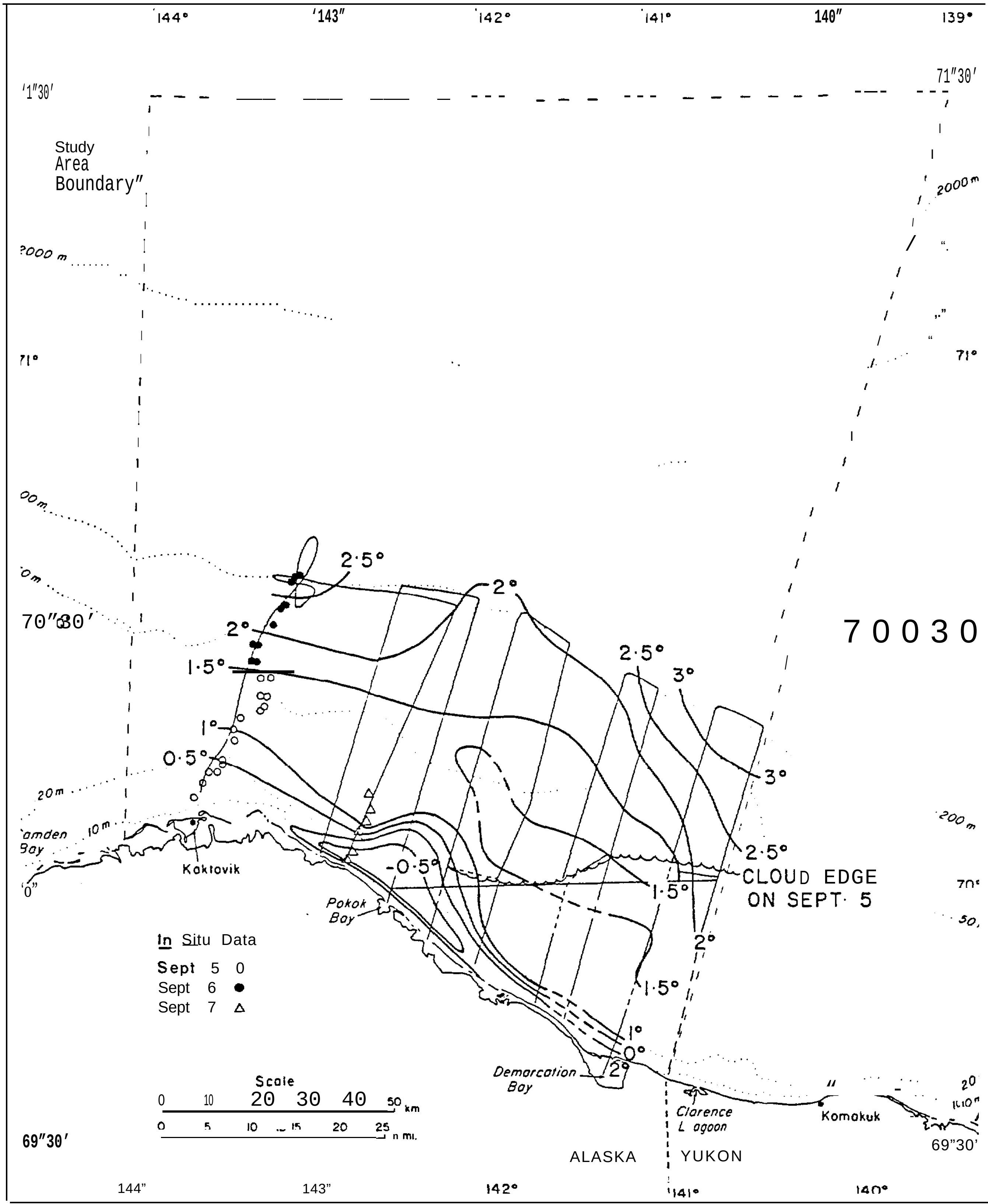


Figure 10. Distribution of sea surface temperature (°C) in the eastern Alaskan Beaufort Sea on 5-6 September 1985, as measured with an airborne radiation thermometer. Symbols indicate location of boat-based temperature measurements used for calibration.

Surface temperatures across the broad expanse of the shelf between the 20 and 50 m depth contours were in the range of 1 to 2°C, with water as warm as 3°C at the northeast corner of the surveyed area (Fig. 10). The northern section of the study area (water >200 m deep) was not surveyed on 5-b September because of persistent fog.

Water Color.--No water color data were obtained on 5 September because of the combination of extremely low light levels under heavy overcast and equipment malfunctions on this first flight (remedied later in the flight). Good data were obtained under overcast skies on b September.

Water color varied relatively slowly over the study area on b September. The variability was probably a result of variation in dissolved organics and suspended particulate matter of riverine origin. The shapes of the reflectance spectra, similar to those shown in Figure 6, indicated that surface chlorophyll concentrations were very low everywhere in the study area. As indicated earlier, comparison of reflectance data from this study with similar calibrated water color data for the Canadian Beaufort Sea (Borstad 1985) suggests that pigment concentrations were less than 0.5 mg m^{-3} everywhere away from the coast. In the bright green turbid waters along the shore and in the barrier lagoons, concentrations my have reached 1 mg chlorophyll m^{-3}.

Apart from a band of very turbid and bright green water within a kilometer of the coast, there was a dark clear blue water mass off Pokok Bay (R640 indicates a secchi transparency of about 13 m) and a gradation to more turbid waters farther offshore (Fig. n). North of the shelf break, the turbidity contours roughly followed the isotherms, with the most turbid water found in the northeast corner of the surveyed area. A secchi transparency of about 4 m is inferred for this water mass.

Survey on 12-13 September 1985

Sea Surface Temperature.--On 12 September we surveyed the continental slope area (200-2000 m contours), and on 13 September we surveyed most of the shelf (0-200 m contours}. There was a gap in the nearshore coverage just north and east of Kaktovik because of a request to avoid overflights of

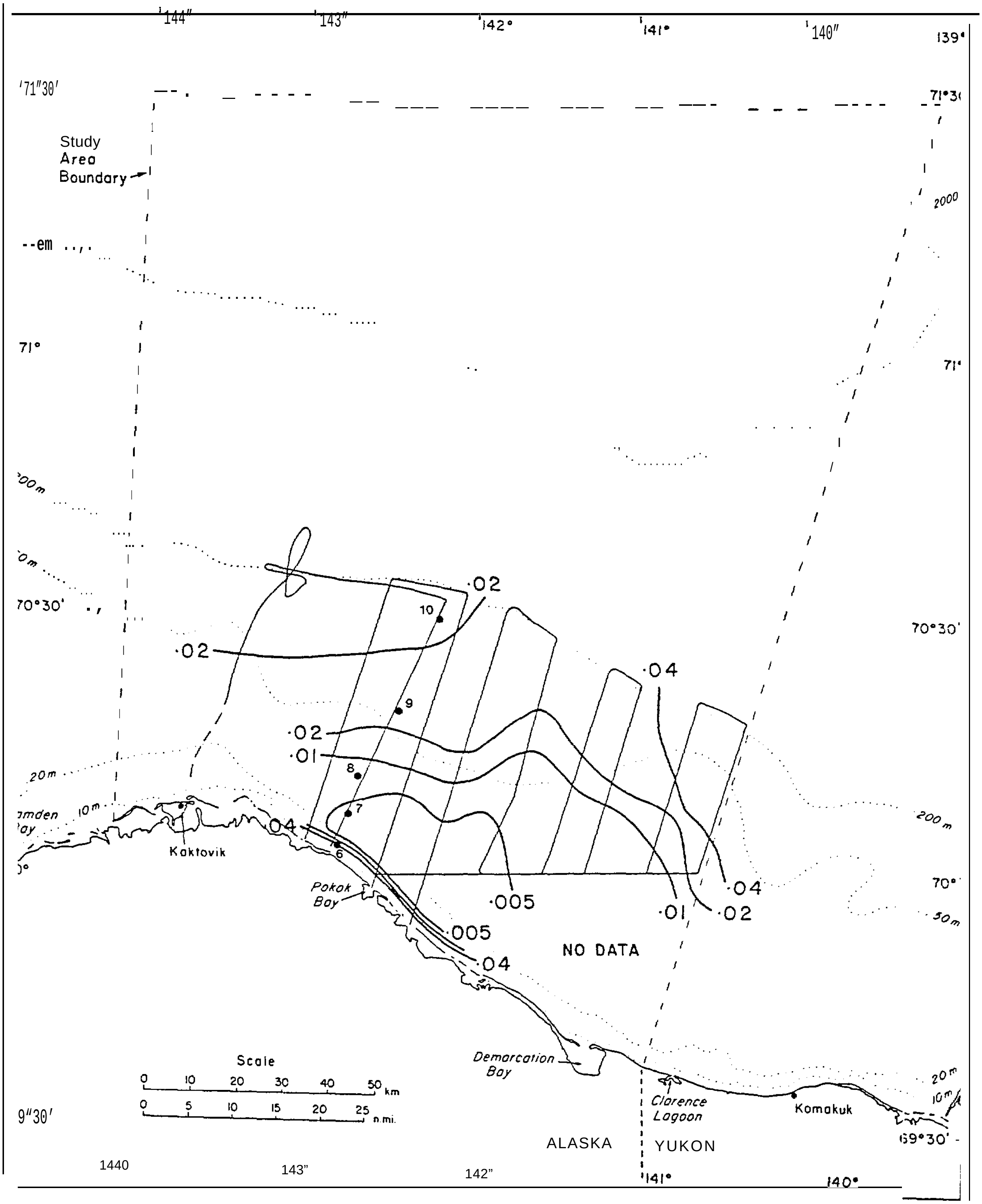


Figure 11. Distribution of the Red reflectance index R640 in the eastern Alaskan Beaufort Sea on 6 September 1985, as measured with the 10S spectrometer. R640 increases with increasing turbidity of the upper water column. Symbols indicate location of ship stations that provided *in situ* secchi measurements for calibration.

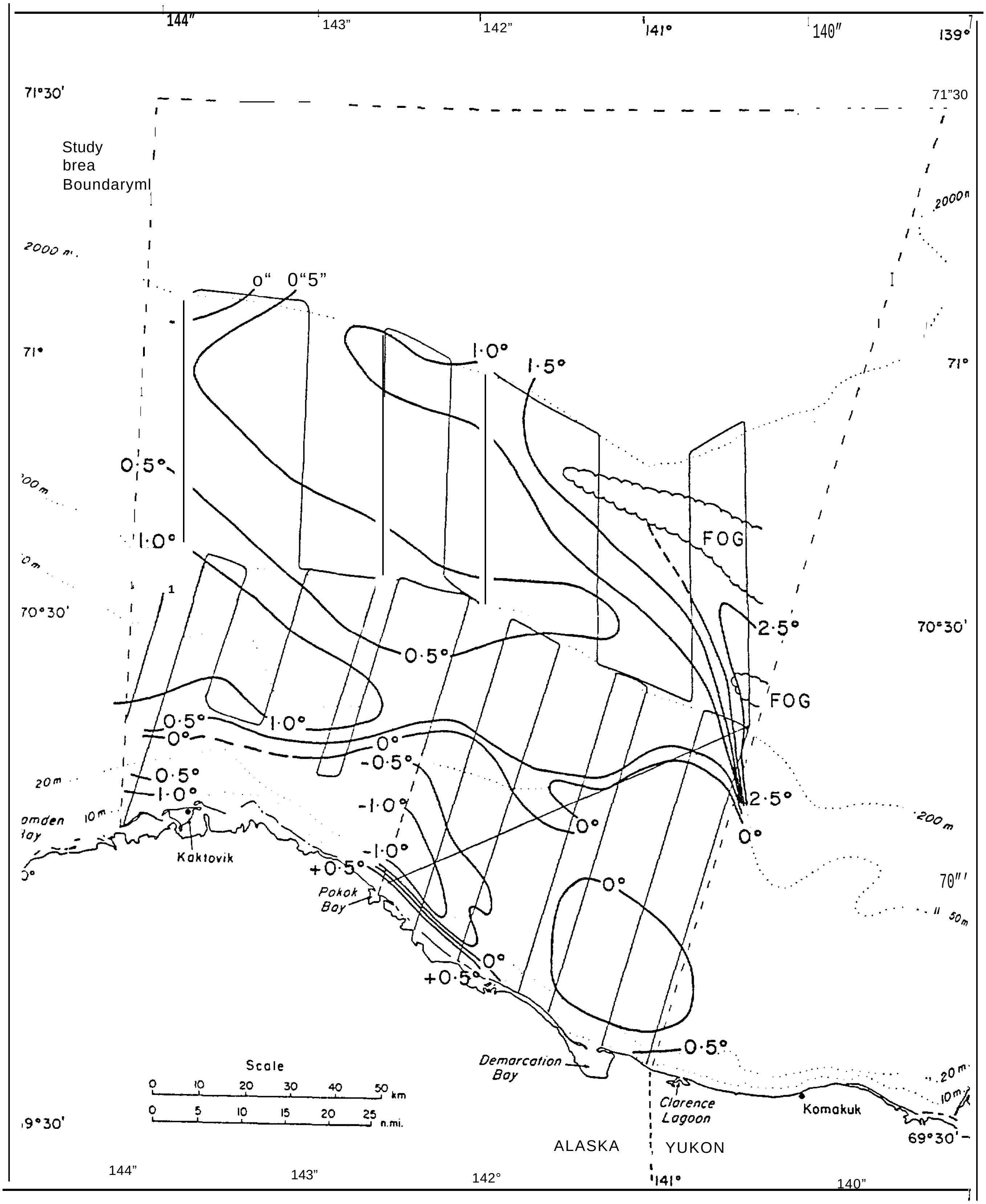
whaling operations near Kaktovik. However, it appears that the narrow band of water warmer than +0.5°C was still present all along the coast, except in the vicinity of Demarcation Bay (Fig. 12). A patch of water colder that -1.0°C was still located north of Pokok Bay. Small widely scattered bits of ice were observed throughout this cold water, but were more concentrated (10-20% brash) along the southern edge of the cold water. This diffuse 'string' of brash ice extended across the south ends of all but the easternmost three transects. At the south end of transect 4, the ice was not separated from the shore by warm turbid water, but piled up against the beach in a band about 100 m wide.

As on 5-6 September, the surface temperatures over the shelf were lower than those over deeper water farther offshore. A front roughly following the 50 m isobath separated shelf waters colder than about 0°C from water warmer than +0.5°C to the north. Water as warm as 3°C was encountered on offshore portions of the easternmost transects, and in many places was associated with mist and 'sea-smoke'.

The eastern half of the shelf (where surface temperatures were less than 0°C) was covered by extensive slicks that were visible from the survey aircraft. In most cases these were not associated with a temperature or color change, but their orientation was consistent with the general southeast-northwest trend of the isotherms. An eddy 4 to 5 km in diameter was visible in a slick pattern near the south end of transect 2 off Demarcation Bay. The eddy was in a pool of slightly warmer water; it may have represented the center of a large gyre in this area.

Fewer slicks were noted over the western half of the shelf. Waters deeper than about 50 m were warmer than 0°C and separated from colder waters inshore by an oceanographic front that was visible from the aircraft as a change in surface roughness.

Water Color.--During the 12-13 September survey, isopleths of the R640 turbidity index roughly followed the isotherms, with the warmest waters in the north and east being the most turbid and those in the west being clearer (Fig. 13). Inferred secchi transparencies were near 14 m in the cold



Figure' 12. Distribution of sea surface temperature ("C) in the eastern Alaskan Beaufort Sea on 12-13 September 1985, as measured with an airborne radiation thermometer.

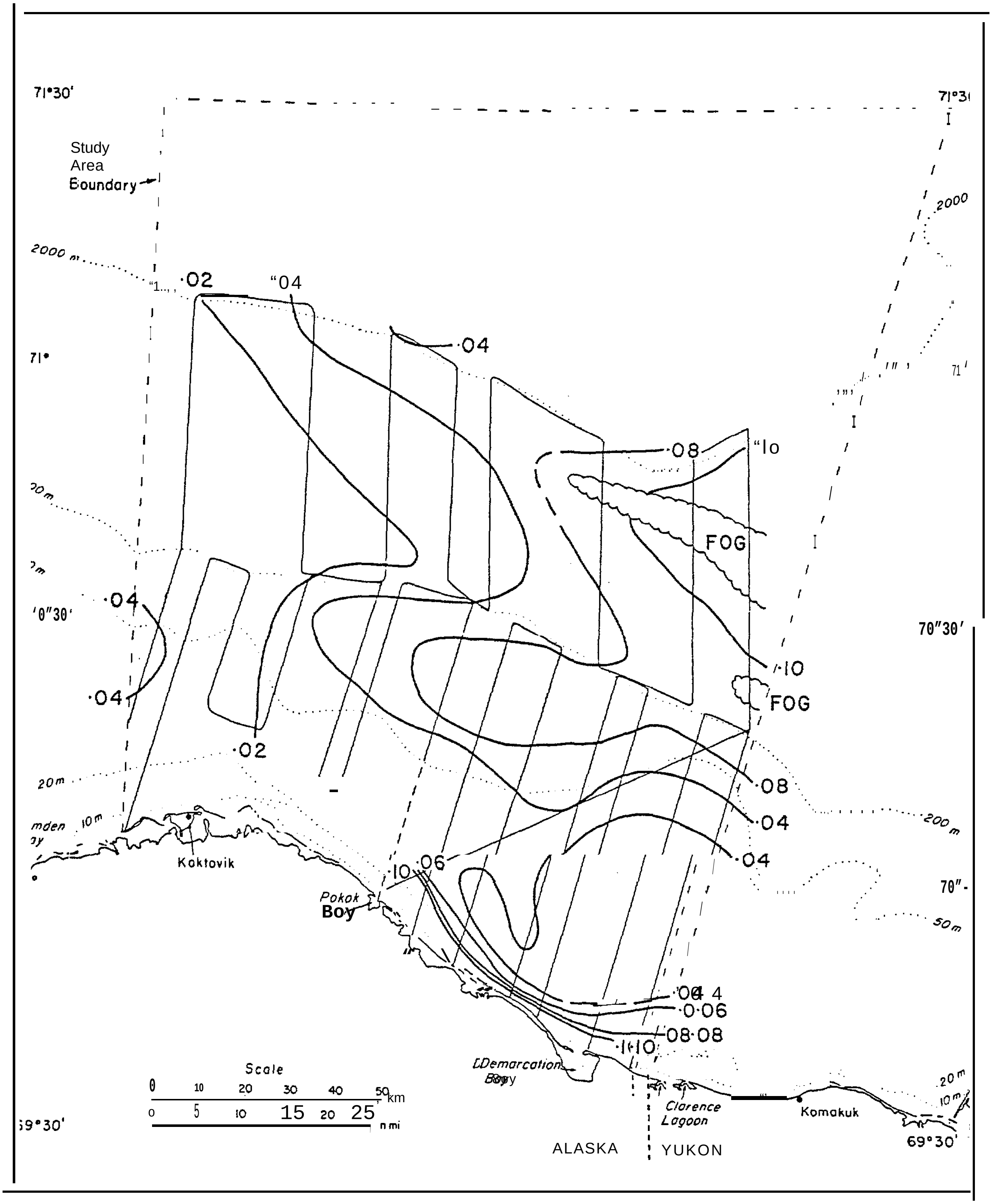


Figure 13. Distribution of the Red reflectance index R640 in the eastern Alaskan Beaufort Sea on 12-13 September 1985, as measured with the 10S spectrometer. R640 increases with increasing turbidity of the upper water column.

blue waters off Demarcation Bay, and 3 or 4 m in the northeast. Two tongues of elevated turbidity were evident extending into the study area from the east. We interpret these as extensions of the Mackenzie River plume, which during late August 1985 was directed into the study area by a prolonged period of strong easterly winds (G. Borstad, unpubl. satellite imagery).

Discussion

The airborne data have not yet been vigorously compared to in situ observations, but by themselves they indicate that the study area can be divided roughly into two sections. The area over the shelf was colder, clearer and generally less affected by the Mackenzie River runoff than were deeper waters off the shelf. The nearshore water mass was separated from more riverine waters farther offshore by a thermal gradient and a water color gradient extending across the study area near the 50 to 200 m isobaths. A sharp front with a thermal gradient of up to 2°C within a kilometer was observed near the shelf break in the eastern part of the study area.

There was some evidence of a clockwise eddy off Demarcation Bay at the time of the 12-13 September survey. This evidence included the observation of a large eddy in the surface slick patterns, and the fact that the brash ice was piled up on the beach near Demarcation Bay but was ~1 km offshore farther west.

The results of the airborne surveys are consistent with the major circulation and water mass features described in our earlier literature review (LGL and Arctic Sciences 1985). The wind regime in the southern Beaufort Sea during the last half of August and first half of September 1985 was generally easterly, with a brief period of southerly winds on 12 and 13 September. As a result of this wind forcing, a large plume of warm and turbid water moved westward out of Mackenzie Bay during August. Our airborne observations indicate that this plume remained across the northern portion of our study area until at least mid September.

The earlier literature survey pointed out that satellite data for this area are biased to easterly and southerly wind regimes because cloud cover prevents satellite observation on most occasions with westerly winds. Our experience in September 1985 confirms that the cloud restrictions on satellite viewing are indeed severe. Even with constant easterly winds during the first two weeks of September most of the the North Slope experienced heavy overcast and fog, with only a short period of clearing on the 12th and 13th associated with the passage of a weak high pressure cell. Although satellite data for 1985 have not yet been examined in detail, we do not expect to obtain useful images for 2 to 12 September. The aircraft and boat data will therefore provide the only indication of oceanographic conditions during that cloudy period. This, plus the fact that the airborne spectrometer is sensitive to smaller water color variations than is the satellite sensor, and can recognize chlorophyll fluorescence if it is present, justifies the use of the airborne system for this project.

The improvements made to the 10S spectrometer during this period allowed real-time processing, which proved to be very worthwhile. The real-time processing and display greatly improved the ability of the operators to calibrate the system in the aircraft, and to recognize, locate and remedy the electronic noise problems encountered during the first flight. The real-time capability also provided the capability to direct the boat toward oceanographic features detected by the airborne instruments.

We expect that satellite data will be available from 13 and 18 September, and possibly for one or more days in the 22-27 September period. Digital satellite data from these clear days will be evaluated in the annual report on 1985 work. The satellite data for the entire Beaufort Sea on 13 September should help place the airborne remote sensing data from 12-13 September into a broader perspective. Satellite data from 18 September should be especially interesting, because that date followed a period of strong westerly winds.

BOWHEAD DISTRIBUTION AND ACTIVITIES*

Introduction

The Western Arctic population of bowhead whales migrate westward through the study area in early autumn while en route from their summering areas in the Canadian Beaufort Sea to their wintering grounds in the Bering Sea (Fig. 1). Aerial surveys in recent years have shown that a few bowheads occur in the study area during August of some years, but that bowheads do not become common there until September. Migration through the area is largely completed by mid October (Ljungblad et al. 1984, 1985). Particularly during the early stages of westward movement through the study area, some of the whales do not travel strongly and consistently westward. At least some whales continue to feed at this time. up to 1984, definite observations of feeding bowheads within the study area were confined to waters less than 200 m deep, and mainly to waters less than 50 m deep (Ljungblad et al. in press). "However, based on repeated sightings of bowheads (not necessarily the same individuals) in certain areas over periods of days, it is possible that feeding sometimes occurs in deeper waters (LGL and Arctic Sciences 1985).

To determine the extent and nature of utilization of the study area by feeding bowheads, it is necessary to determine how many bowheads are present at various times in the late summer-early autumn period. It is also necessary to determine the activities of these whales, including the proportion that are feeding and the nature of feeding (e.g. near-surface, water column, near bottom).

Previous aerial surveys have provided valuable data on the routes and timing of bowhead movements through the study area, and some observations of feeding. However, absolute numbers of whales within the study area at various times have not been estimated. Quantitative estimates are difficult to obtain because allowance must be made for the many whales that are inevitably missed

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* By W. John Richardson, B. Würsig and G. Silber.

during aerial surveys. To do this, correction factors must be determined to allow for whales at the surface but not seen, and for whales below the surface. Such correction factors have been derived for aerial surveys of the Canadian summering grounds in 1981 (Davis et al. 1982), but not for other areas or years.

As part of the 1985 study of bowheads in the eastern Alaskan Beaufort Sea, we conducted aerial surveys to determine the distribution of bowheads in the study area, including their distribution relative to oceanographic factors and food availability. We also obtained aerial observations of bowhead behavior in order to evaluate the proportion of the whales that were feeding, feeding modes, and other aspects of behavior. Data on the durations of surface-dive cycles were acquired to assist in deriving a correction factor for submerged whales missed during aerial surveys. Calibrated vertical photography was used in order to determine the sizes of the whales utilizing various parts of the study area. Because many bowheads are individually recognizable from natural markings, the photogrammetry program can also provide refighting data, and thus help determine whether specific individuals linger in certain preferred feeding areas. We were prepared to radio-tag several whales in order to provide additional data on residence times within feeding areas and other topics. However, concentrations of feeding bowheads were absent from the study area during the period when boat-based work was possible, so radio-tagging was not possible in 1985.

Methods

All aircraft-based work was done from a Twin Otter aircraft equipped with a GNS500 Very Low Frequency navigation system, bubble windows, and camera port. During the first half of September 1985, airborne remote sensing equipment was also aboard the aircraft (see above).

Systematic and Reconnaissance Surveys

Systematic aerial surveys of the southern 2/3 of the study area (from the shore or barrier islands north to the 2000 m depth contour) were attempted weekly during September. Because previous observations of feeding whales within the study area were in water <200 m deep, more effort was devoted to the 0-200 m depth stratum than to the 200-2000 m stratum. A series of transects was established within each of these two strata. The nearshore zone was divided into 12 strips 10.6 km wide (plus a triangular 13th strip). The offshore zone was divided into eight strips 18.5 km wide. Within each strip, one transect was selected at random (Fig. 14). The 13 'nearshore' transects totalled 832 km in length; the eight 'offshore' transects totalled 428 km in length.

Systematic surveys of the nearshore area were completed four times, on 5-6, 13, 18 and 25 September. Fog precluded an offshore survey on or near 5-6 September, but much or all of the offshore area was surveyed on 12, 19-21, and 27 September.

Surveys of these transects were at an airspeed of 200 km/h. Survey altitude was 305 m above sea level when the ceiling permitted, or at 153 m a.s.l. when the ceiling was too low to allow surveys at 305 m. On the right side of the aircraft, two observers were always present, one in the co-pilot's seat and another adjacent to a bubble window two seats farther back. On the left side, one observer was adjacent to a bubble window two seats behind the pilot, and another observer was sometimes present in a rear seat. The two right-side observers observed independently; their sightings were not announced to other observers. This was done in order to develop a correction factor for missed whales, based on the method of Magnusson et al. (1978) as applied to bowheads by Davis et al. (1982). For each bowhead sighting, the number of whales, presence of calves, heading, estimated speed, and lateral distance from the flight line were dictated into a tape recorder. Lateral distances were measured with inclinometers.

In addition to the systematic surveys of the nearshore and offshore strata, we conducted numerous other reconnaissance surveys in these areas from 5 September to 3 October 1985. These reconnaissance surveys were done while we were searching for whales for purposes of behavioral observations and photogrammetry. The great majority of the bowhead sightings during this project were obtained during the reconnaissance flights, which were concentrated in areas where the probability of whale sightings was

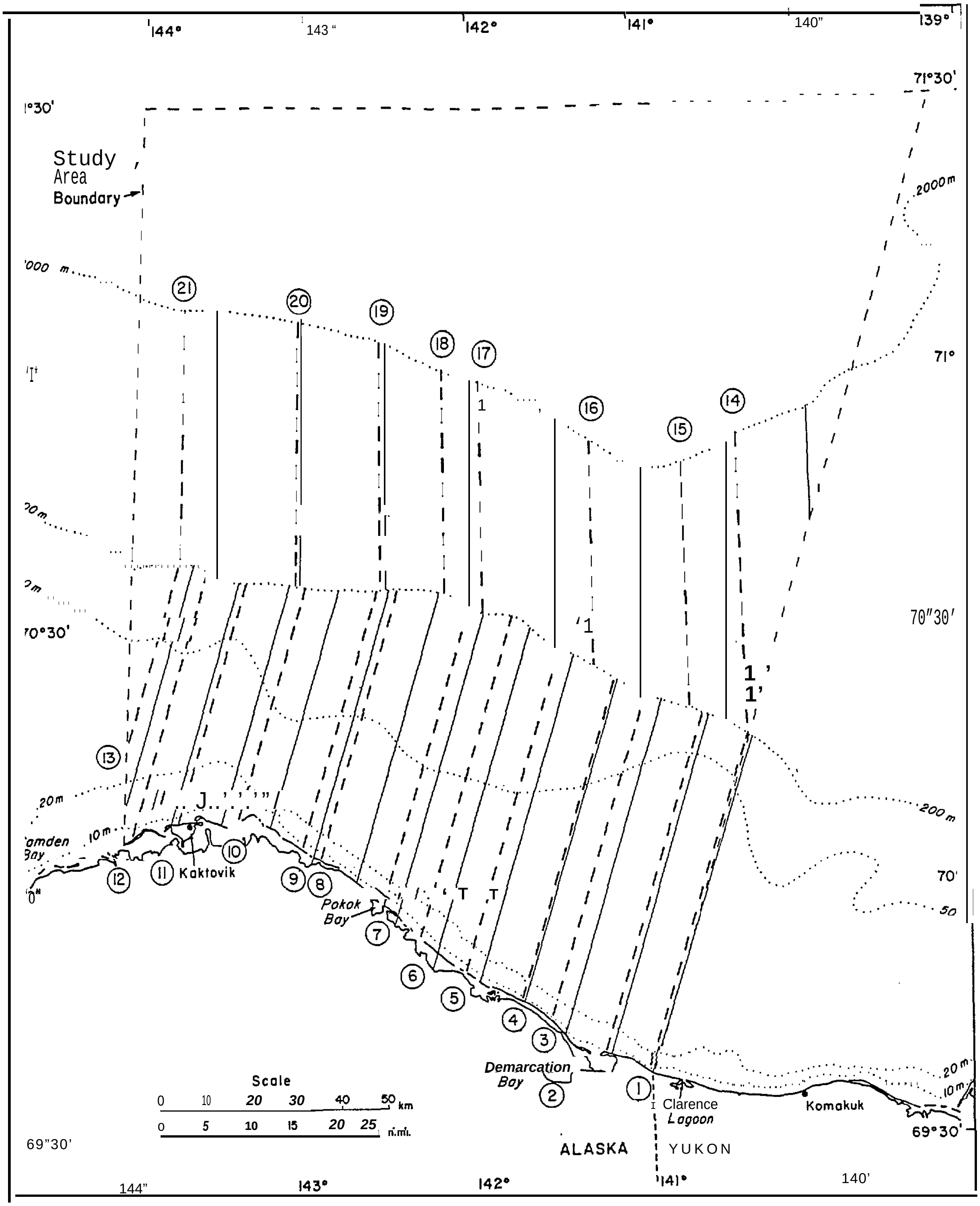

Figure 14. Locations of 21 aerial survey transects (dashed lines) within the study area. For each strip demarcated by continuous lines, one transect was selected at a random location (see text).

highest. The flight lines and sightings are presented in this section. Furthermore, while the boat chartered for this Project was moving along its transects during the 4-18 September period (Fig. 2), an observer maintained a watch for bowheads; none were seen along the boat transects.

Several other studies of bowhead whales in the Canadian and Alaskan Beaufort Sea were conducted during the late summer and autumn of 1985. Some of these studies included aerial survey coverage of parts of our study area. Detailed results from those studies are not yet available. In particular, surveys by the Naval Ocean Systems Center (NOSC) were coordinated with our surveys in order to provide some coverage of deep waters north of the area surveyed by us. NOSC and other investigators also obtained some coverage of our study area before and after our study period. When these data become available, they will be used to supplement our results. In this preliminary report, we include only a few general references to the data acquired during other studies.

Behavioral Observations

On **eleven** occasions, we used the aerial observation procedures described by Würsig et al. (1984) to observe the behavior of bowheads (Fig. 15). Four observers in the Twin Otter aircraft circled high above the whales. Aircraft altitude was 457 m or (on 13 Sept) 61(I m, either of which is high enough to avoid significant aircraft disturbance (Richardson et al. 1985b). Two observers dictated behavioral observations into a tape recorder, and a third observer operated a video camera whenever whales were at the surface.

During 9 of 11 behavioral observation sessions, underwater sounds near the whales were monitored by sonobuoys (AN/SSQ-51A, Spartan Electronics). The fourth observer watched for whales 'outside' the area being circled and operated sonobuoy receiving equipment. Hydrophore depth was normally 18 m, but in shallow water we used specially modified sonobuoys with a 9 m hydrophore depth setting. Sonobuoy signals were received and recorded via calibrated equipment (Greene 1985) so that received levels and spectral characteristics can be measured.

Radio Telemetry

The crew of the boat chartered for the project included J. Goodyear, a specialist in the application of radio-telemetry techniques to field studies of feeding by baleen whales. He provided two types of small radio "tags, both of which can be deployed onto whales by crossbow. The primary type was a small (7 x 1.6 cm) 'capsule' tag that penetrates no more than 10 cm into the blubber, leaving only a fine wire antenna protruding from the surface. The 'back up' tags were 'remora' tags of the type that Goodyear has deployed onto many humpback whales. Both types of tags could be monitored from either the boat or the project aircraft. During one transmission test during this project, radio signals from a capsule tag were received aboard the survey aircraft at range 70 km when the aircraft was at altitude 550 m.

Because very few bowhead whales were present within the study area during the ice-free part of the field season, there were no opportunities to radio tag whales within a concentration of feeding whales. One attempt was made to tag a single bowhead, but conditions were not favorable and it was not possible to approach closely enough (within 20 m) to deploy the tag. We remain convinced that the tagging approach described above would be successful if applied in an area where bowheads were concentrated and feeding.

Photogrammetry

After most behavioral observation sessions and on a few other occasions, we photographed bowhead whales using the calibrated vertical photography technique of Davis et al. (1983). The aircraft flew back and forth above the group of whales at an altitude of about 145 m, attempting to pass directly over whales when they were at the surface. Photographs were taken using a hand-held Pentax 6x7 cm camera with 105 mm lens pointed vertically downward through a camera port in the floor of the aircraft. Some photographs were on Ektachrome 200 color reversal film. However, when lighting was poor under heavy overcast or late in the day, Ilford XP1 black and white film was often used. As each photograph was taken, the altitude of the aircraft was read from a radar altimeter. A total of 233 photographs of whales was obtained at 10 locations (Fig. 15).

On two occasions, the same approach was used to obtain calibration photographs of a target of measured dimensions. Comparison of the estimated lengths with the known dimensions will be used to derive correction factors for bias attributable to the radar altimeter or other factors.

Results

Occurrence of Bowheads in the Study Area, Autumn 1985

Data from NOSC surveys during August 1985 are not yet available to us, but there apparently were very few sightings within our study area during August. Surveys of the Canadian Beaufort Sea in August 1985 revealed numerous bowheads in the Mackenzie Bay area (LGL, unpubl. data). During August, some bowheads were present as far west as Komakuk (1400), just east of our study area.

Little surveying was possible during the 1-10 September period because of frequent low cloud. However, no bowheads were seen during a systematic survey of the nearshore part of the study area on 5-6 September (Fig. 16). Survey conditions were relatively good, and there was virtually no ice in the areas surveyed. In contrast , very large numbers of bowheads were present east of the study area (138°W) in southern Mackenzie Bay on 6 September; others were seen close to shore as far west as Komakuk (140°20'W) on 8 September (LGL unpubl. data).

During the next period of good weather within the study area, 11-13 September, we conducted a systematic survey of the nearshore and offshore strata (Fig. 17). Again, there was virtually no ice in the surveyed area. Only two bowheads were sighted during the systematic survey. Furthermore, NOSC surveyed in the ‘far offshore’ part of our study area (waters >2000 m deep) on 12 September; no bowheads were seen there. On each of 11, 12 and 13 September, several bowheads were found during surveys west of our study area (LGL and NOSC unpubl. data). Thus, migration through the study area had

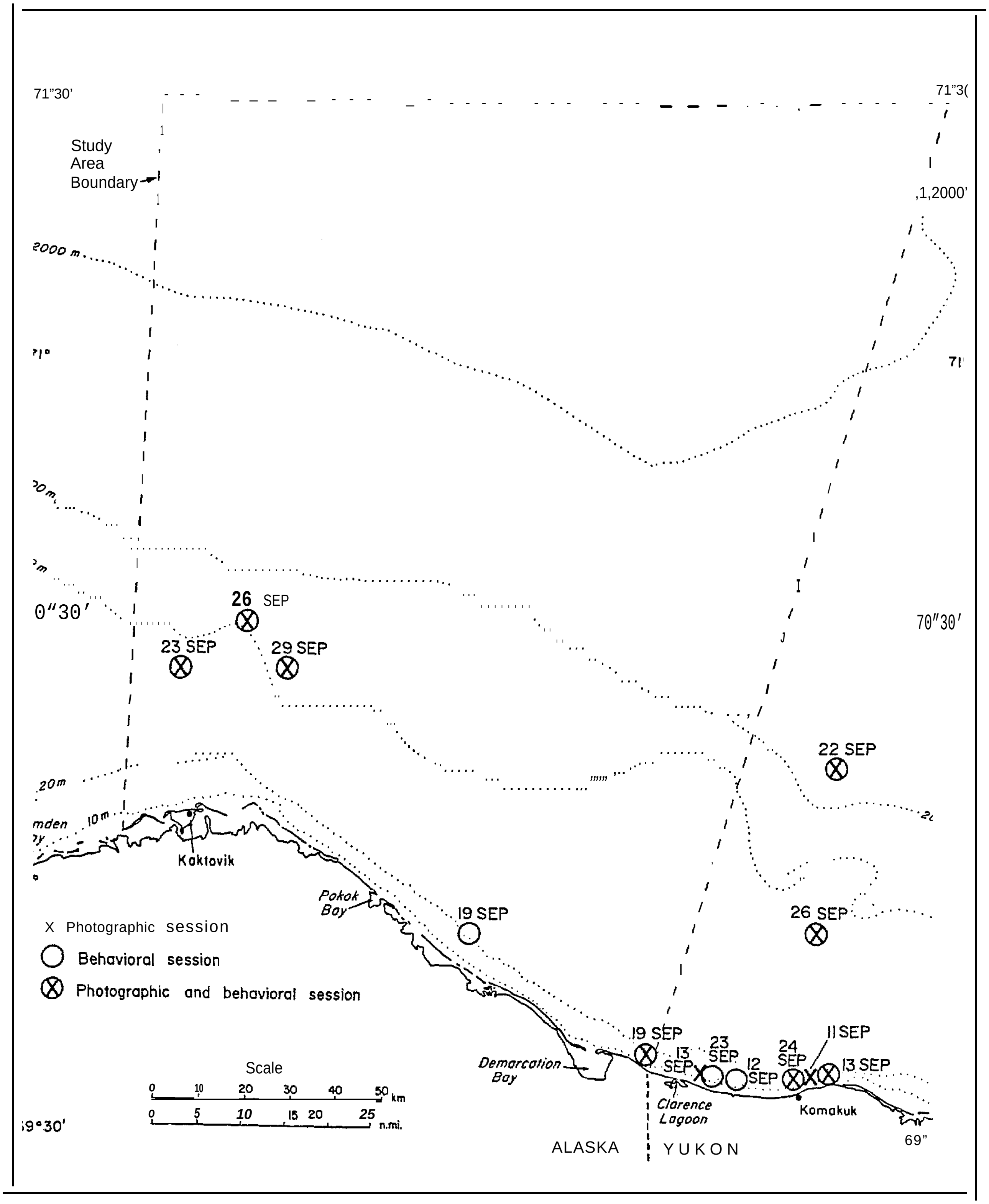

Figure 15. Locations where behavior of bowheads was observed, and where calibrated vertical photographs were acquired, September 1985.

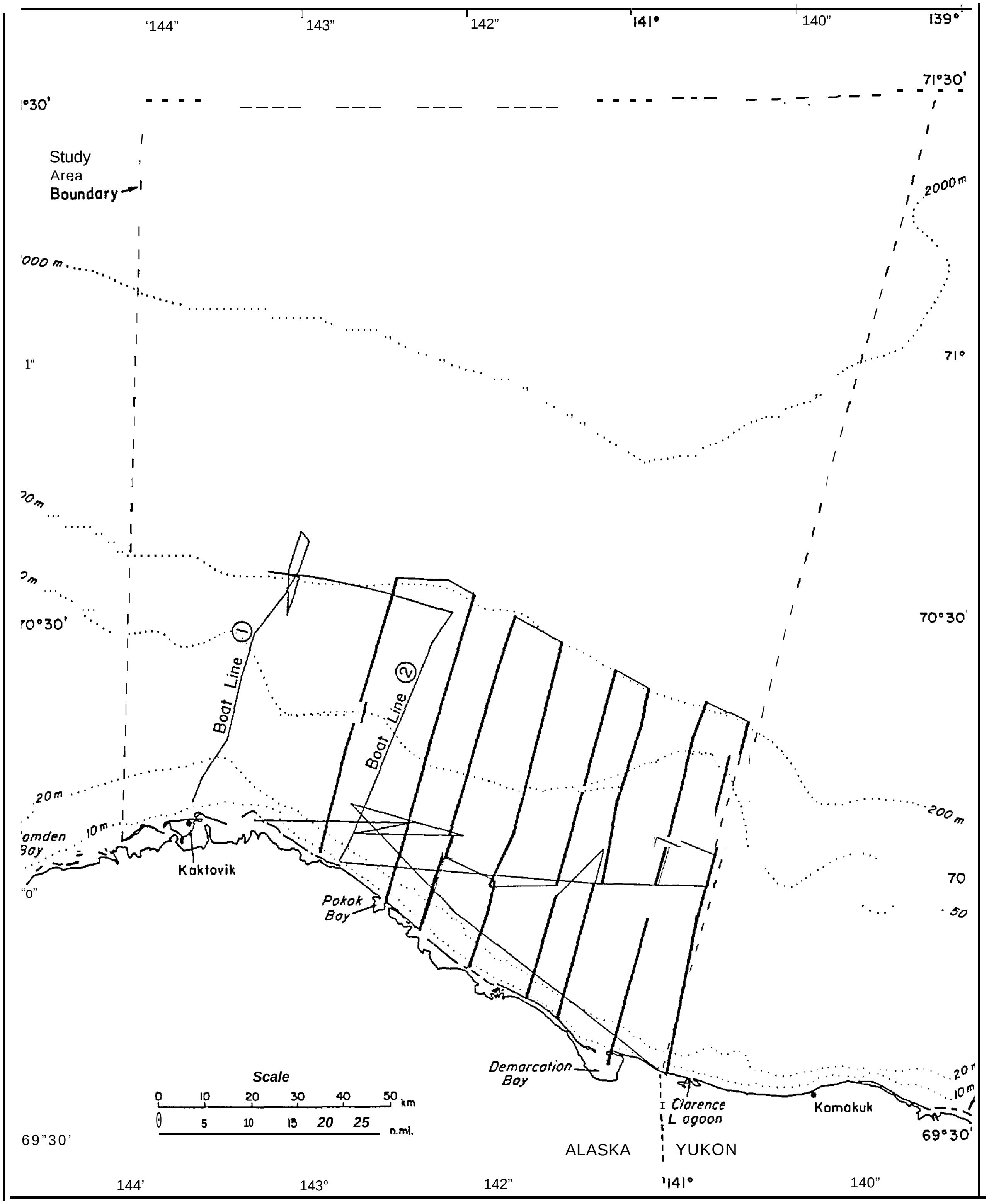

Figure 16. Aerial survey routes, 5-6 September 1985; no bowheads were seen. Thick lines show flight routes during systematic surveys of the predefine transects (cf. Fig. 14). Thin lines show routes during reconnaissance surveys and during aerial surveys along two transects that were also surveyed by boat.

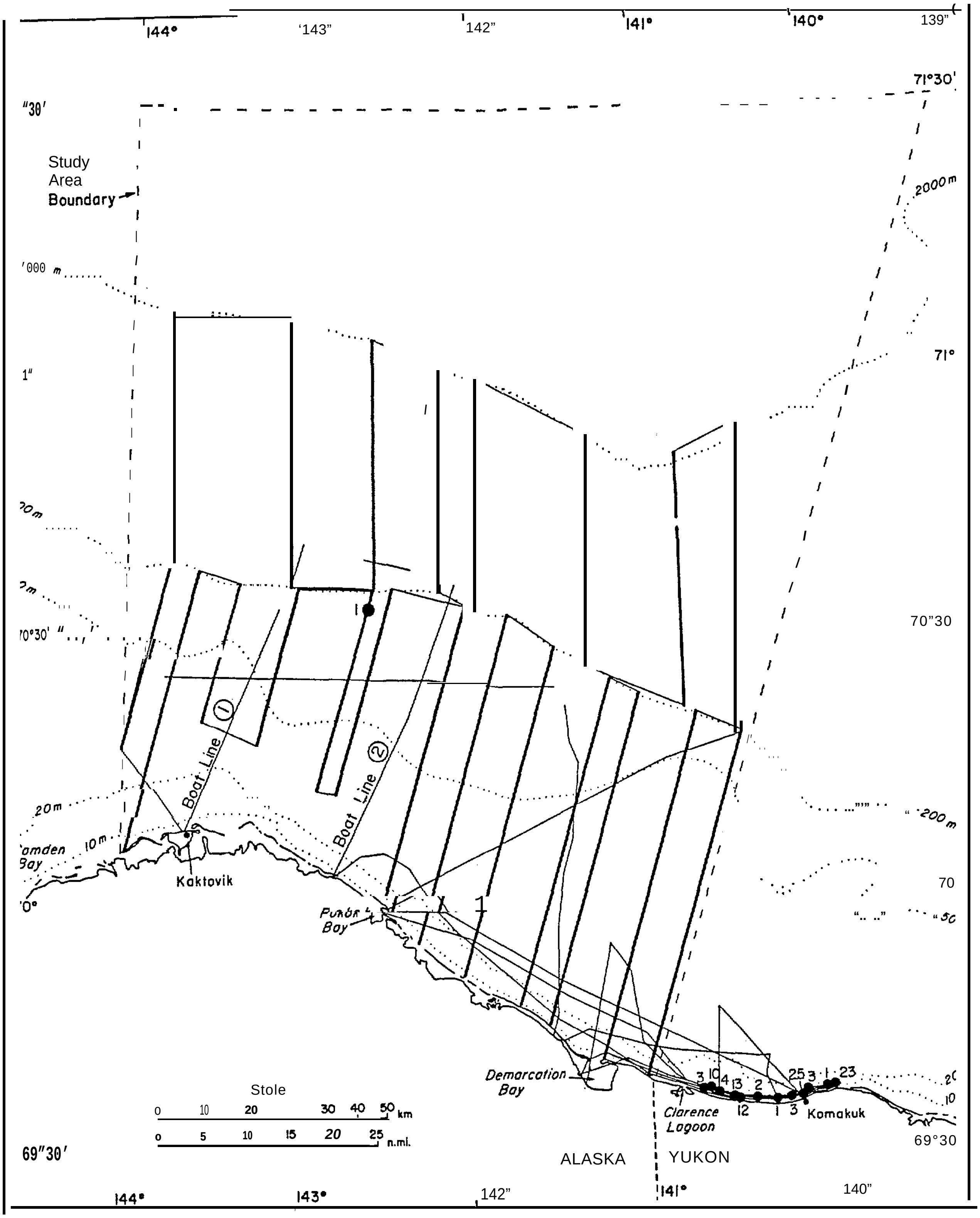

Figure 17. Aerial survey routes and bowhead sightings, 11-13 September 1985. Presentation as in Figure 16.

apparently begun by this time. However, the numbers in and west of the study area were low when compared with numbers seen farther east. We conducted three flights for behavioral observations and photogrammetry on 11-13 September. We found many bowheads close to shore just east of our 'official' study area, from Clarence Lagoon eastward (Fig. 17). Some of these whales were feeding near the surface; they were not traveling strongly westward. Numerous whales were still present farther east in the Kay Point area (138°W) on 13 September (LGL unpubl. data).

After a period of poor weather on 14-17 September, surveys resumed on 18 September. By 18-21 September, much of our study area (but not the SE corner) contained extensive pack ice, which was blown into the area by strong westerly winds on 16-17 September. Three bowheads were seen along the 13 nearshore transects, plus three more along the 200 m contour near the north end of the westernmost transect. No bowheads were seen along the six offshore transects that we were able to survey, and NOSC saw none north of the 2000 m contour during a 'far-offshore' survey on the 19th. Considerable additional reconnaissance was done along the coast and in the area of open water in the southeastern quadrant of the study area. The only additional sightings were on 19 September, when we found two whales close to shore near 142°W, plus eight whales traveling strongly westward near Demarcation Bay (Fig. 18). Interestingly, only one whale was seen along the shore in the Clarence Lagoon to Komakuk area on 18, 19 and 21 September (this study; NOSC). A few bowheads were seen west of our study area on 19 and 20 September (LGL unpubl. data).

Additional reconnaissance surveys were flown on 22-24 September, and whales were found in three main areas (Fig. 19): along the coast between Komakuk and Clarence Lagoon, well offshore north of Komakuk, and north of Kaktovik. These whales were not moving strongly westward, and many were observed or suspected to be feeding. Whales were seen in each of these three areas on two different days in the 22-24 September period, and whales were seen north of Kaktovik on later days as well (Fig. 20). When the vertical photos acquired in these areas are analyzed for resightings, we hope to determine whether some individual whales remained in these areas for more than one day, and whether some of the individual whales near Komakuk had been

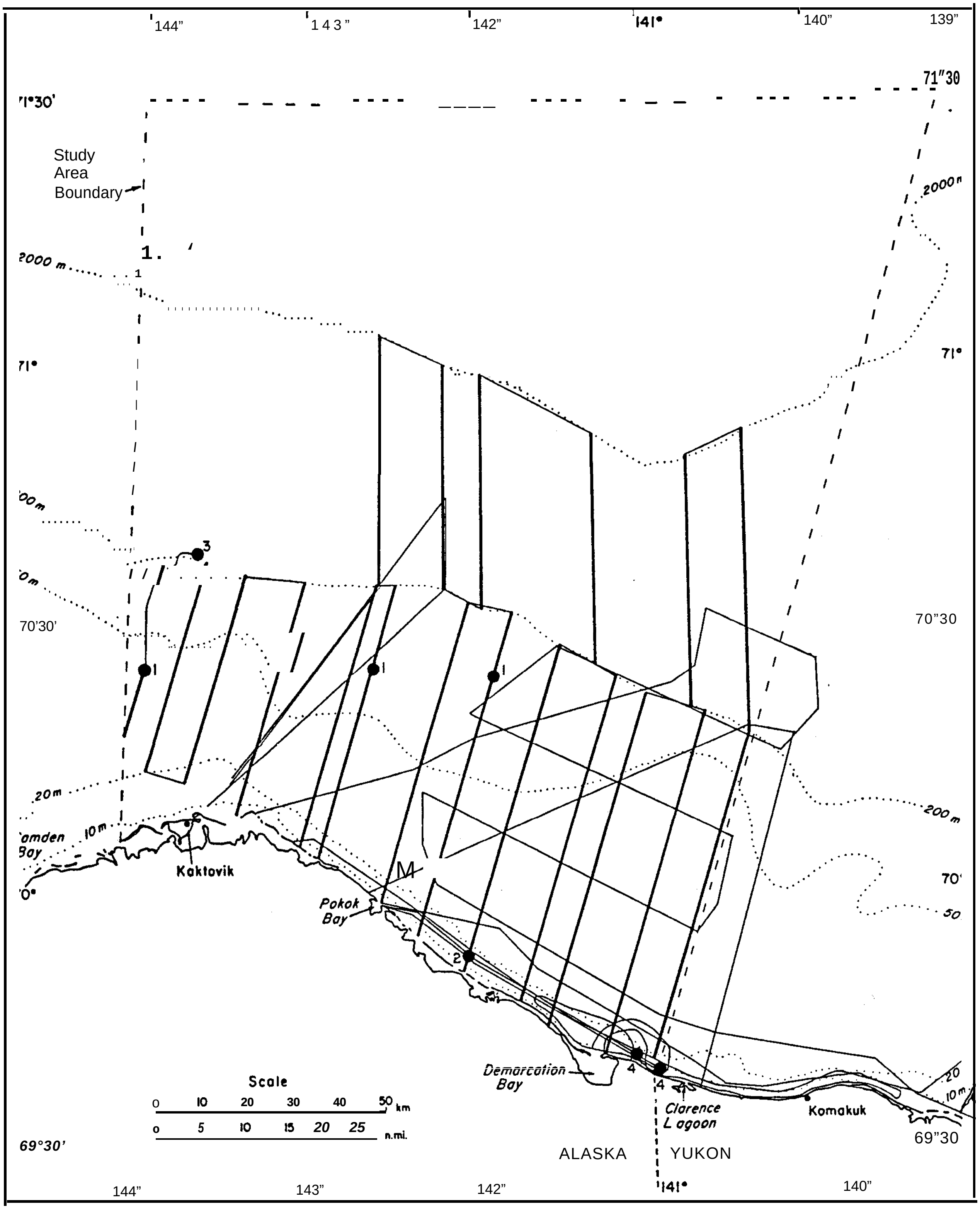

Figure 18. Aerial survey routes and bowhead sightings, 18-21 September 1985. Presentation as in Figure 16.

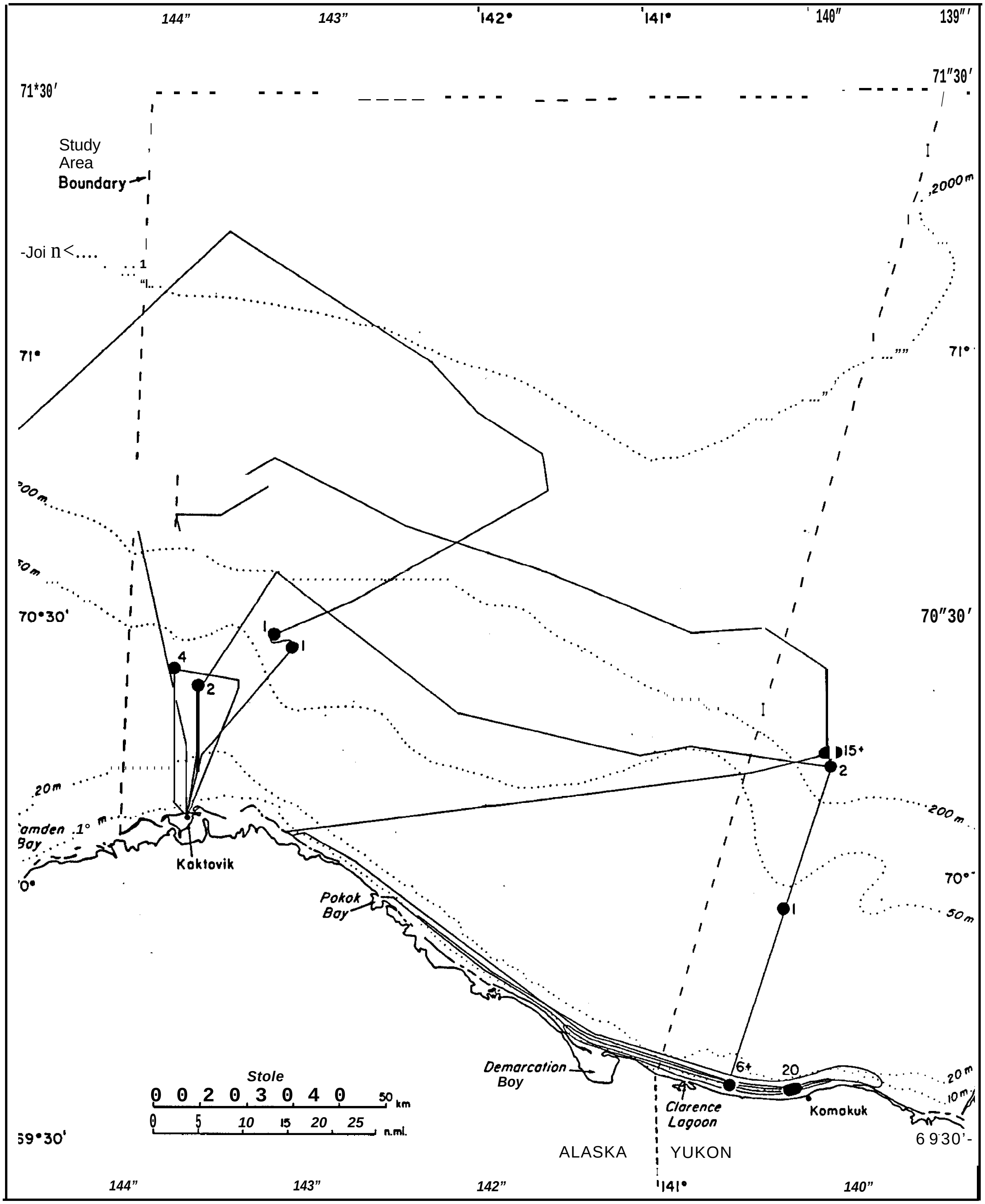

Figure 19. Aerial survey routes and bowhead sightings, 22-24 September 1985. Presentation as in Figure 16.

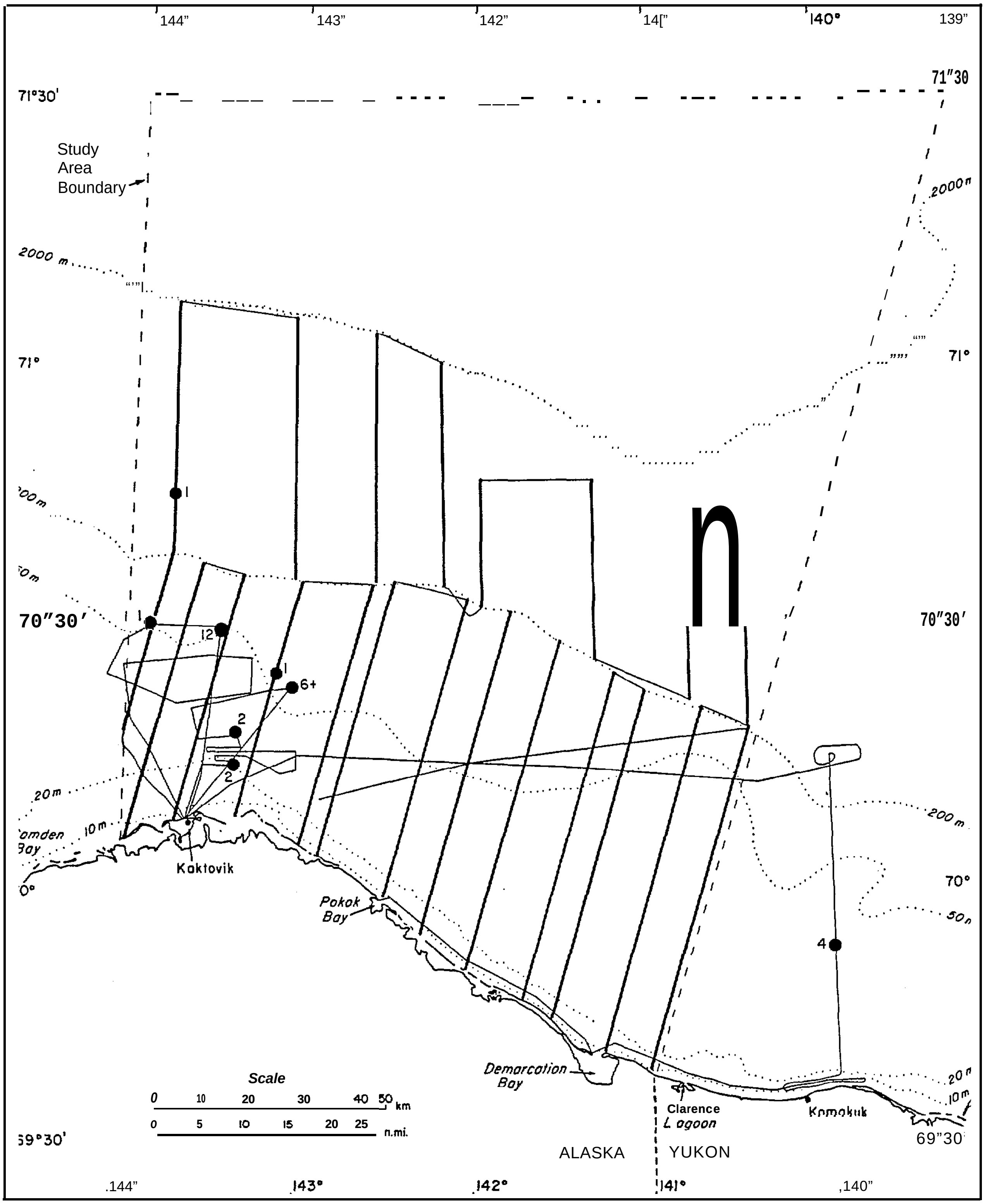

Figure 20. Aerial survey routes and bowhead sightings, 25-29 September 1985. Presentation as in Figure 16.

there earlier in the season. A few whales were seen west of our study area on 22 and 23 September (LGL unpubl.).

The next systematic survey of the nearshore and offshore strata was on 25 and 27 September. Only two bowheads were seen along the survey lines, most of which were over extensive pack ice. However, there were several sightings north of Kaktovik during reconnaissance surveys on 25-29 September (Fig. 20, plus additional sightings by NOSC). Ice cover had become less extensive there than it was during the previous week. There was also a sighting of four whales north of Komakuk, east of the 'official' study area (Fig. 20). Whales were suspected to be feeding in the water column in both areas. NOSC saw a few whales at Komakuk on 24-25 September, but no whales were found when we searched there on the 26th. Whales were seen well to the west of our study area on 25 and 26 September (LGL and NOSC unpubl.).

Poor weather conditions from 30 September to 3 October resulted in little survey coverage (Fig. 21). However, the lack of sightings north of Kaktovik on 1 and 3 October suggested that the numerous whales present there in late September (Fig. 19, 20) had departed.

Our field program ended on 3 October, but other surveys provided some coverage until 20 October. Near-daily surveys in the Mackenzie Bay-Herschel Island-Komakuk areas of the Canadian Beaufort Sea from 7 to 20 October showed that bowheads were still present in Canadian waters, in apparently diminishing numbers, until about 18 October. LGL personnel sighted three bowheads within the present study area (near 142°W) during flights on 9 and 12 October. Coverage of our study area by LGL and NOSC on 16-20 October revealed no bowheads even though there were a few stragglers farther east until at least 18 October.

Activities of Bowheads in the Study Area, Autumn 1985

We observed the behavior of bowhead whales during 11 behavioral observation sessions on eight different days in September 1985, generally between Kaktovik and the Komakuk DEW site (Fig. 15, Table 6). Most observation sessions lasted 1-2 h, and most ended when the observation

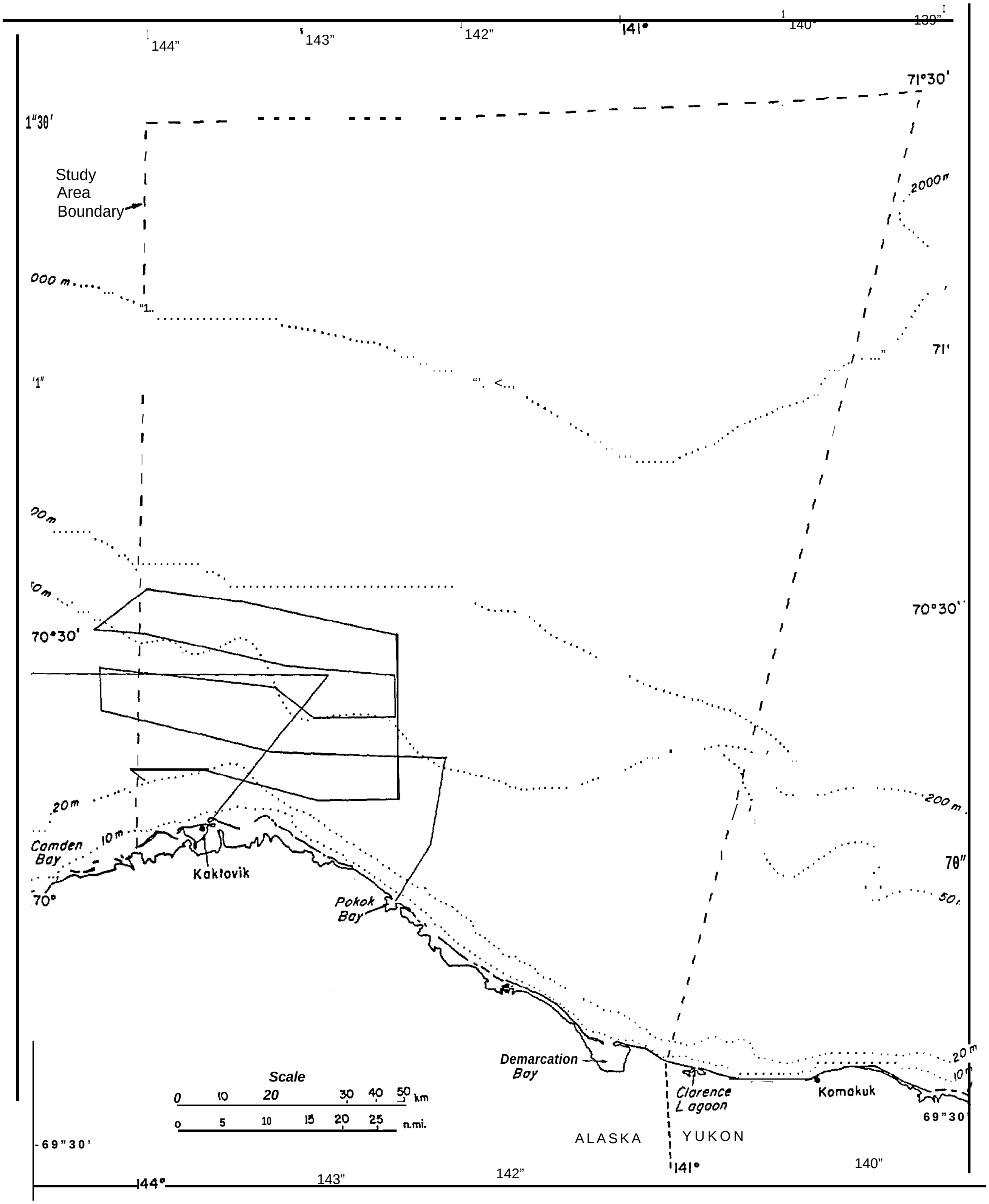

Figure 21. Aerial survey routes and bowhead sightings, 1 and 3 October 1985. Presentation as in Figure 16.

aircraft descended to obtain photogrammetric data on the same group of whales. Total observation time was 15.2 h. Most behavioral sessions were either slightly east of the 'official' study area or in loose ice offshore from Kaktovik within the study area (Fig. 15). Water depths ranged from about 8 to 280 m, although all but one session was in water $\leq$50 m deep. Sea state was usually Beaufort 1.

Whales were encountered in aggregations covering from about 4 km^2 (in a small area surrounded by ice) to about 40 km^2. The estimated mean number of whales in these areas was 14 $\pm$ s.d. 10, with a range of 3-40. Estimated number of whales within our circle of observation was 5 $\pm$ s.d. 2 (range 1-10).

Feeding or suspected feeding in the water column (Würsig et al. in press) occurred on all days of observation and during 10 of 11 observation sessions. Whales fed at or near the surface, with mouths open, during four sessions; on two of these occasions several whales traveled side by side in small echelons. Three of the four cases of near-surface feeding were along the shore near Komakuk; one was NE of Kaktovik on 29 Sept. Water-column feeding was suspected to occur when whales dove for generally long times in an area. It may have occurred during at least seven sessions (Table 6). Four of these cases were within the 'official' study area; three were slightly to the east. We saw a few defecations, which are assumed to be indicative of recent feeding. We saw no mud plumes, which would have indicated bottom feeding (Würsig et al. in press).

Whales definitely traveled toward the west on only one day, on 19 September around noon near Demarcation Bay. This was the only observation session for which we had no evidence of feeding, and it is likely that the whales were migrating. During four additional sessions, there was slow-to-medium speed travel westward, perhaps indicative of a low level of migratory activity. These cases were on 13, 23 (2 sessions) and 29 September. We observed surface feeding by the traveling whales on 13 September, and we suspected that water-column feeding was occurring during the other three sessions of possible westward movement. Thus, bowheads may feed as they travel slowly westward through the study area.

Table 6. Summary of behavioral observation sessions, 1985.

Date 1985	Behav. Obs. Sess. #	Location	Time & Length of Obs.	Number of Whales: in Circle	Number of Whales: in General Area*	Feeding	Traveling	Socializing	Orientation	Speeds of Travel
12 Sept	1	69°37'N 140°30'W	1628-1817	5-8	10-15 in 15 km²/30-40 in 40 km²	near surface/ some in echelon/ some defecation		some—low level	random	slow & medium
13 Sept	2	69°37'N 140°07'W	1608-1704	7-10	20-30 in 15 km²	near surface	possibly	some—low level	more than half orient west	slow & medium
19 Sept	3	69°54'N 142°00'W	0930-1219	1	3 in 20 km²	possible water column			random	Slw
19 Sept	4	69°40'N 141°00'W	1231-1300	4 (400 m dia.)	8 in 10 km²		strongly directed		nearly all west	medium
22 Sept	5	70°14'N 139°56'W	1044-1250	6-8	15-20 in 20 km²	possible water column		up to 5 socializing	random	no or slow
23 Sept	6	69°37'N 140°38'W	1127-1213	3 4	5-8 in 20 km² (no calves)	possible water column	possible slow travel		most west or south-West	Slew
23 Sept	7	70°24'N 143°45'W	1640-1815	4-6	4-6 in 4 km²	possible water column	possible slow travel		most west or north-west	no or slow
24 Sept	8	69°36'N 140°13' W	1058-1143	4-6	15-25 in 40 km²	echelons; many open mutts; defecation			random	no or slow
26 Sept	9	69°52'N 139°58'W	1034-1200	4	4	possible water cohn			random	mostly slow
26 Sept	10	70°29'N 143°23' W	15afl-1630	4-6	13-18 in 20 km²	possible water column			random	no to slow
29 Sept	11	70°23' N 143°02'W	0926-1034	5-6	12 in 20 km²	possible water column; near surf ace	possibly		most west	slow & medium

Table 6 (Concluded).

Behav. Obs. Sess. #	Dives: Duration	Dives: Distance	Size Classes*	Disturbance	Vocalization	Photos	Depth (Approx.)	Sea State	Ice
1	general impression ≥5 min. (1 measured dive = ~7 min.)	unknown	no calves or small whales seen; assure? mainly adults	faint seismic, probably not disturbing	some	no	10 m	1	0%
2	general impression ≥5 min. (1 measured dive = ~8 min.)	!dmU.'ln	no calves or small whales seen; assume mainly adults	moderate to faint seismic, possibly disturbing	none heard	yes	8 m	1	0%
3	about 20 min.	about 200-300 m	apparent adult	potentially boat, plain, zodiac	unknown (no sono-buoy)	no	20 m	1	1%
4	unknown—appears to be short blow sequence & shallow dives	unknown	1 calf, seven others	none known	unknown (no sono-buoy)	yes	13 m	2	1%
5	about 30 min.	100-700 m	most whales apparent adults, + 3 calves and 1 subadult	seismic	yes	yes	280 m	1	.5(E
6	general impression ≥5 min. (no measured dives)	unknown	apparent adults, 1 small whale, no calves	none	yes	no	14 m	2-3	5%
7	general impression ≥5 min. (no measured dives)	unkn	apparent adults, no calves	loud seismic; post seismic	yes	yes	40 m	0	65%
8	1 measured diva of 73 s; others unknown	75 m during l; others unknown	many possible subadults; no calves	faint seismic, some engine noise	yes, occasional	yes	15 m	0	1% brash 100% grease
9	avg. B-roil-l. dives by 2 calves & 1 adult	2 estimates of 250 m each	2 adults, 1 small & 1 large calf	seismic	yes, many	yes	40m	1	<1% old 100% grease
10	2 measured dives = 18,0 min.; others unknown	2 estimates of 250 m each	most apparent adults; 2 calves	none	yes, many	yes	42 m	1	5% old, 50% new gray, 45% grease
11	dives of inter-mediate length; ~2-16 min.	1 estimate, ~200 m	most apparent adults, 2 calves, 1+ subadult	faint seismic	yes, many	yes	50 m	1	40% old

* Size class information is based on visual observations rely. For the eight behavioral observation sessions when calibrated photos were taken, precise size data will be available at a later date.

We observed social interactions, generally of low intensity, on 12 and 13 September. On 22 September, social activity occurred more frequently. On all three days, socializing occurred during observation sessions when surface feeding or possible water-column feeding **was** also occurring in the same general area.

During periods of possible water-column feeding, dives were usually longer than 5 min in duration, and sometimes up to about 30 min. During at least four sessions, some dives were longer than 15 min. Distance traveled underwater between surfacings could not be ascertained often, but estimated distances ranged from 75 to 700 m during possible water-column feeding and near-surface skim feeding. No estimates of distances traveled during dives were obtained on 19 September, when whales definitely were traveling west.

Calves were seen during five sessions. Three of these cases were in the 'official' study area (19, 26, 29 Sept) and two were just to the east (22, 26 Sept). On three occasions, **two or** more **calves** were present in the general area of observation. At times during periods of suspected water-column feeding, we saw lone calves at the surface, presumably waiting there while their mothers fed below. On some occasions, small whales--presumably subadults--were noted. Sizes of whales will be determined precisely when the calibrated photographs acquired during this project are analyzed.

Whales were heard to vocalize during 8 of 9 observation sessions when sonobuoys were used. During the afternoon of 26 September, high-frequency calls were heard while at least one calf was alone at the surface with the mother presumably feeding in the water column. We suspect that these unusual calls may have come from the calf, but this is not certain. A similar case was noted in August 1982 (Würsig et al. 1983).

Seismic pulses were detected during 7 of the 9 occasions when underwater sounds were monitored near whales. In most cases the pulses were weak, and in no case was the seismic vessel close enough to be noticed from the observation aircraft. On one occasion (24 Sept), whales near Komakuk DEW site were exposed not only to faint seismic pulses but also to faint engine noise, possibly from generators at Komakuk. On another occasion (19 Sept), whales were exposed to a maneuvering boat ('Annika Marie') and zodiac during an unsuccessful radio tagging attempt. In no case was the behavior of the whales believed to be seriously affected by any of these sources of potential disturbance.

Photogrammetric Data

A total of 233 photographs of whales were acquired by G. Miller of LGL during this study. These photos were obtained at ten location/date combinations (Fig. 15). Almost all of these photographs were calibrate and vertical, suitable for length measurements as well as recognition of individuals from their natural markings. Most photos were of a single whale, but some contained images of 2-5 animals. The 233 photos contained a total of 267 whale images. At three locations, two of which were within the official study area north of Kaktovik, photographs of mothers and/or their calves were obtained. For most of these photographs, the water was quite clear and the sea state was low or moderate (O-2). Consequently, a high proportion of the images should be usable. As of the date of writing, the photographs have been developed. However, analysis of whale sizes and individual identities has not begun. It should be noted that, in addition to the 233 photos acquired during this project, other whale photos were acquired in the Komakuk area earlier in the summer during another LGL project. These will be considered along with the present photographs to analyze residence times of whales in the Komakuk area.

Discussion

Bowhead whales occurred in our study area at least intermittently from the second week of September to the second week of October, with peak numbers being present in late September. Some of the whales seen in the study area as late as late September were apparently feeding. Within the 'official' study area, feeding bowheads were seen most commonly in waters over the continental shelf north and northeast of Kaktovik. In contrast to some earlier years, no concentrations of feeding bowheads were found in the southeastern part of the study area near Demarcation Bay. However, slightly farther east, near and north of Komakuk, bowheads were present for a prolonged period and often were feeding.

We have not yet attempted to **estimate the number of bowhead whales** within the study area at various times in 1985. However, very few bowheads were sighted during the systematic surveys. Numerical estimates based on those surveys will undoubtedly be small even after allowance for submerged and other missed whales. The number of bowheads within the study area during the autumn of 1985 never approached the numbers present at certain times in some earlier years (e.g. late September 1982, Johnson 1983).

It was apparent from the 1985 behavioral observations that bowheads often did feed while within the study area. There was some evidence of feeding while whales were traveling slowly westward as well as at times when they were remaining in specific areas. When analysis and integration of the 1985 data is completed, we will have a more comprehensive view of the importance of the study area to feeding bowhead whales in 1985.

This study is scheduled to continue in 1986. If more whales utilize the study area in the autumn of 1986 than did so in 1985, it may be possible to evaluate whether variable utilization of the study area is related to variable food abundance.

ENERGETICS OF BOWHEADS*

LGL and Arctic Sciences (1985) identified many areas of uncertainty in their preliminary analysis of the energy needs of bowhead whales. Recently acquired data relevant to bowhead energetic computations are described below.

1. Photogrammetric data collected in the study area in 1985 will yield the first quantitative information on the sizes and categories of whales that use our Study area in autumn. The energy needs of different categories of whales vary considerably. It will be useful to know if the whales that feed in the study area are a random sample of the population, or whether specific categories of whales

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* By D.H. Thomson, LGL Ltd.

are over-represented. Also, photographs of whales taken during this and other studies conducted in 1985 will provide more data on the dimensions of bowheads. Such data are needed for the computation of weights and surface areas of bowheads of various lengths.

2. The caloric content of zooplankton collected during this study and a similar study in the Canadian Beaufort Sea in 1985 is being determined. These data will provide the first comprehensive set of caloric data for zooplankton from the Beaufort Sea. These data will be used to calculate the rate of food intake necessary to meet the energetic requirements of bowheads.

3* Behavioral observations of bowheads in and near the study area in September 1985 produced data on respiration rates and limited data on dive times and distances traveled while underwater. These data will be used to refine theoretical estimates of the energy needs of bowhead whales.

4. Bowhead tissues for carbon isotope analysis were not acquired in autumn 1985 at Kaktovik, since no bowheads were taken there during the study. However, usable tissue samples may be available from whales taken in previous seasons. We hope to acquire some of these samples in sufficient time for presentation of results in the final report on 1985 work. Zooplankton samples from the study area and from the Canadian Beaufort Sea were collected in 1985, and are being analyzed for isotopic composition. It is hoped that isotopic analysis will yield information on the amount of feeding that occurs during winter and during the spring and autumn migrations (Schell et al. 1984).

5. The importance of the study area to the whales that feed there depends on their durations of stay. Some data on residence times may be available through the results of the 1985 aerial photogrammetry.

6. Because concentrations of feeding whales were not present in the study area during the period of boat-based observations in 1985, we do not have data on the biomass of zooplankton at locations and times where whales were feeding. A zooplankton study conducted by LGL in the Canadian Beaufort Sea in 1985 did sample near feeding whales. However, these data may be of only limited applicability to our study area because samples were collected slightly earlier in the season (late August), because the categories of whales may have been different from those that used our study area (to be verified through the results of the 1985 aerial photogrammetry in both areas), and because the zooplankton populations in the two areas appear to have been rather different (see Zooplankton section).

In summary, various types of data collected during the 1985 field season will improve our estimates of the energetic requirements of bowhead whales. Some of these data should be available in time for consideration in the updated energetic analysis that will appear in our final report on 1985 studies. From an energetic point of view, high priority tasks for the second year of the study in 1986 include determination of zooplankton biomass near feeding whales, determination of residence times of whales in the study area, and acquisition of bowhead whale tissues for isotopic analysis.

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