NOAA Technical Memorandum NMFS F/NWC-98

Hydroacoustic Monitoring of Prey to Determine Humpback Whale Movements

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March' 1986

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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HYDROACOUSTIC MONITORING OF PREY TO DETERMINE HUMPBACK WHALE MOVEMENTS

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ABSTRACT

The relationship between humpback whale, *Megaptera novaeangliae*, movements and their prey was studied in southeastern Alaska from late July to mid-September 1984. We used hydroacoustics to determine the density and distribution of prey, midwater trawls to sample the prey, and fluke photography to identify individual whales. Prey were assessed at several specific whale feeding sites in 1983 and 1984 and were monitored in Glacier Bay and Frederick Sound at standard index sites since 1981.

Over 200 different humpback whales were encountered during 1984, of which 181 were photographically identified. Whale concentrations were only found in areas of extensive prey concentrations. The most detailed studies were conducted in Glacier Bay, where 19 humpback whales were identified. Fish were the main prey of the whales in Glacier Bay and in adjacent Icy Strait. Whale movement was common within the bay and between Glacier Bay and Icy Strait. Much of this movement was associated with changes in types, densities, and distribution of prey. Changes in prey have apparently caused a decrease in the use of Glacier Bay by humpback whales.

Most of the whales observed during 1984 were in Stephens Passage, Frederick Sound, and Chatham Strait where the primary food source was deep layers of euphausiids. A positive relationship between number of whales and density of euphausiids was found in Doty Cove, northern Stephens Passage.

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CONTENTS

INTRODUCTION

The humpback whale, *Megaptera novaeangliae*, is a major attraction each year for more than 120,000 visitors at Glacier Bay National Park, These whales are an endangered species protected under the Marine Mammal Protection Act, the Endangered Species Act, and the National Park Service Organic Act. The latter act directs the National Park Service (NPS) to provide for visitor use and enjoyment of resources in Glacier Bay and to maintain those resources for future generations. Of concern to NPS is an apparent decline in whales using Glacier Bay as a summer feeding area. NPS is limiting the number of vessels into Glacier Bay until the factors causing the decline are better understood.

The humpback whale population in the North Pacific was estimated at 15,000 before exploitation by the whaling industry (Johnson and Wolman 1984). Although completely protected since the late 1960's, the present population is estimated at only 1,200 whales (Johnson and Wolman 1984). In Alaskan waters, humpback whales range from Dixon Entrance to the northern Bering Sea, but they are not uniformly distributed. Instead, they congregate to feed in areas rich in prey that include Pacific herring (*Clupea harengus pallasi*), capelin (*Mallotus villosus*), and euphausiids (mainly *Thysanoessa raschii*) (Krieger and Wing 1984). The northern part of southeastern Alaska is a major summer feeding area where 326 individual whales were identified from 1979 to 1983 (Baker et al. 1985). Humpback whales also congregate along the outside coast and in the southern part of southeastern Alaska, but whale research and censuses have been limited in these areas.

Some humpback whales return annually to the same localized feeding areas and become residents (i.e., whales that feed in an area for more than 4 weeks). Glacier Bay is one of these feeding areas. From 1973 through 1977, 10-24 humpback whales were seen in Glacier Bay each. summer, and 10-21 were residents (NMFS 1983). Since 1978, the use of Glacier Bay by resident humpback whales has changed. From 1978 through 1984, 10-23 whales visited the Bay each year, but only 1-7 whales became residents (Baker 1983; NMFS 1983). Reasons proposed for the decrease of resident humpback whales in Glacier Bay were increased vessel traffic and changes in whale prey.

To reduce the potentially adverse effects of vessel traffic on humpback whales, NPS has restricted the number of vessels in Glacier Bay during summer months (June through August) and regulated vessel speeds and traffic patterns where whales feed. In addition, studies. were initiated in 1981 to investigate probable causes of the decrease in whale numbers in Glacier Bay. NPS, in cooperation with the National Marine Mammal Laboratory of the Northwest and Alaska Fisheries Center, funded a three-part program to determine the following: 1) the acoustic environment of humpback whales in Glacier Bay and Frederick Sound (Malme et al. 1982; Miles and Malme 1983); 2) whale behavior in response to vessel traffic (Baker et al. 1982; Baker et al. 1983); and 3) the distribution and abundance of whale prey (Wing and Krieger 1983; Krieger and Wing 1984). Whale prey research was conducted by the Auke Bay Laboratory, NMFS; in 1982, 1983, and 1984. The results of the 1984 prey research, as well as the relationship between humpback whale locations and prey distributions in 1982, 1983, and 1984, are presented in this report.

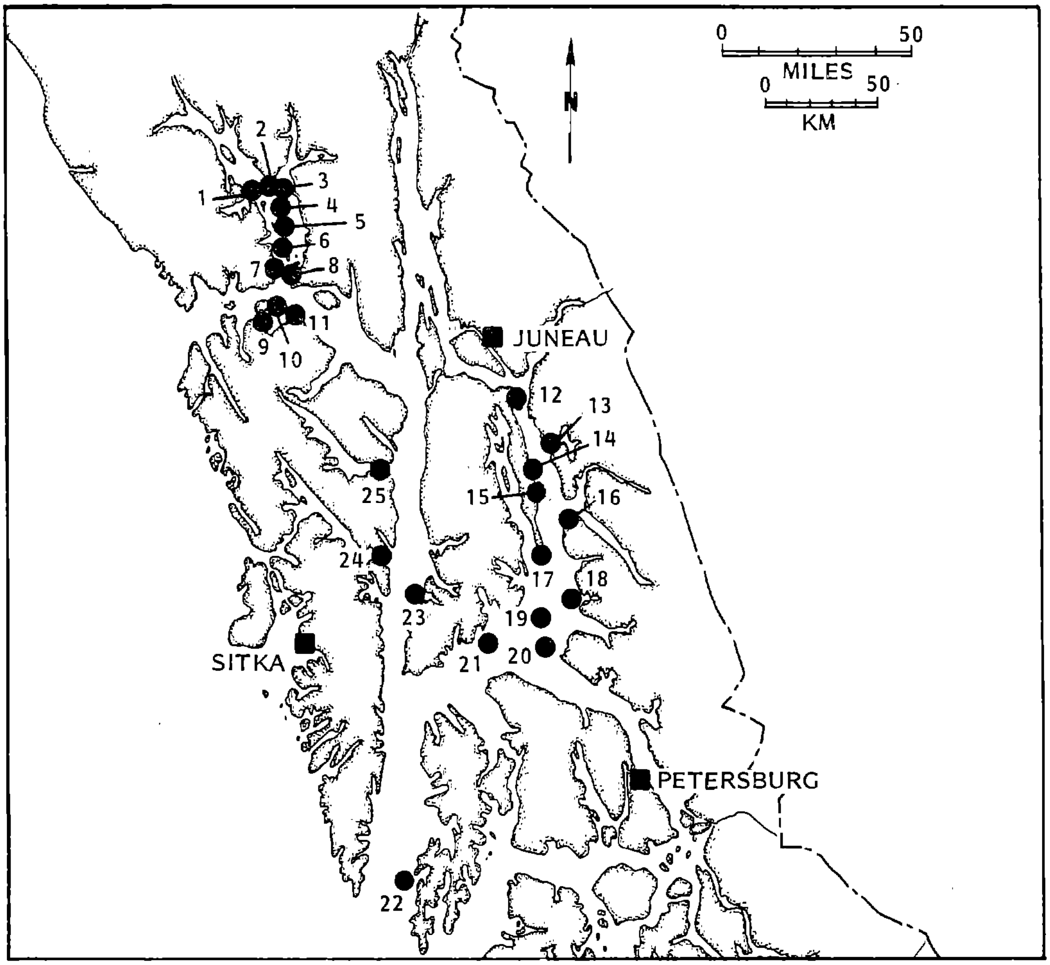
The main objective of the humpback whale prey research in 1981 and 1982 was to monitor seasonal and spatial distributions of prey in Glacier Bay and in Stephens Passage-Frederick Sound. In 1983, an additional objective was to determine types, distribution, and abundance of prey at "specific" humpback whale feeding sites. The 1981, 1982, and 1983 whale prey research produced several findings 1) annual, seasonal, and spatial variations of prey occurred in Glacier Bay; 2) high densities of prey were found at all whale feeding sites; 3) the types of prey differed among feeding sites; 4) fish were the main prey of whales in the Glacier Bay area; and 5) euphausiids were the main prey of most whales observed elsewhere in southeastern Alaska.

To supplement these findings, whale prey research was continued in 1984. The priorities of the 1984 research were as follows: 1) identify specific whale feeding sites in Glacier Bay and in other portions of southeastern Alaska and determine the composition and density of prey at these sites; 2) hydroacoustically assess prey in Glacier Bay for seasonal and annual comparisons with 1982 and 1983 estimates; 4) census and identify whales at feeding sites and characterize their behavior in response to prey and vessels; and 5) characterize the physical and biological oceanographic features of whale feeding sites. The 1984 whale prey study was conducted mainly in the Glacier Bay area but also included sites in Stephens Passage, Frederick Sound, and Chatham Strait (Fig. 1).

METHODS

Vessels

Two vessels were used in the 1984 whale prey study. The _Acona_, a 24 m oceanographic research vessel, was chartered for 60 days from late



GLACIER BAY
1 Geikie Rk
2 Thlingit Pt
3 Sturgess Is
4 Marble Is
5 Willoughby Is
6 Strawberry Is
7 Sitakaday Narrows
8 Bartlett Cove

ICY STRAIT
9 Quartz Pt
10 Lemesurier Is
11 Pt Adolphus

STEPHENS PASSAGE
12 Doty Cove
13 Port Snettisham
14 Twin Pt
15 Pt Glass
16 Holkam Bay
17 Pt Hugh
18 Entrance Is

FREDERICK SOUND
19 Sail Is
20 Five Finger Is
21 Spruce Is

CHATHAM STRAIT
22 Port Malmsbury
23 Whitewater Bay
24 Peril St
25 Tenakee Inlet

Figure 1.--Southeastern Alaska locations where humpback whales were censused, whale prey assessed, or oceanographic samples obtained, 23 July to 15 September 1984.

July to mid-September and used for hydroacoustic surveys, sampling of whale prey, and collecting oceanographic data. The NMFS research vessel Searcher, a 10 m modified gill-netter, was used primarily to locate, census, photograph, and observe humpback whales.

Hydroacoustic Surveys

We used hydroacoustics (echo sounding) to index fish and micronekton and to locate and assess the density of specific whale prey. Hydroacoustic data were collected with a Biosonics[1] echo sounder in conjunction with a 104-kHz 7.5" beam-angle Ross transducer. The transducer was mounted 2 m below the water surface on a stanchion that attached to the side of the research vessel Acona. Support equipment for analyzing and recording hydroacoustic data included a Biosonics echo integrator, a Kaypro microcomputer, an EPC graphic recorde.r, and a Sony audio-digital processor and video-cassette recorder. The integrator converted reflected sound energy to density estimates. The microcomputer stored the integrated data on floppy diskettes. The graphic recorder provided visual recordings of the intensity and depth distribution of the acoustic targets. The video-cassette recorder provided permanent records of the digitized data that could be reprocessed through the integrator and chart recorder.

Biomass estimates of whale prey were determined by echo-integration processing. Echo integration is based on the theory that the average integrated acoustic intensity scattered from targets is proportional to the average density of the targets. The integrator, programmable to

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[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

process echo sounder returns for discrete time-depth intervals, digitized the echo sounder returns, squared the voltage of the digitized signal, calculated a sum-of-squares value, and averaged the output for each time-depth interval. The integrator outputs were measurements of either relative backscattering densities/m3 or absolute densities in units of weight/m^3 or targets/m^3.

Relative backscattering densities are measures of the total sound energy scattered by all midwater targets (zooplankton and fish) and are referenced to an arbitrary scaling factor of 1.0. Backscattering densities were collected for three successive years to determine annual and seasonal fluctuations in the density of prey in whale feeding areas. Densities were collected at 30 separate depth intervals consisting of twenty-nine 5 m strata for depths between 5 and 145 m and a single stratum for depths between 145 and 200 m (depths referenced to the transducer! face). Sequence lengths were 5 minutes long (600 pings) at which time an average integrated value was derived for each of the 30 depth strata. Sequence densities within each transect were averaged to obtain transect densities, and transect densities were weighted by transect length to obtain area densities.

Absolute densities are measures of the biomass of either euphausiid layers or fish schools at whale feeding sites. Conversion of relative densities to absolute densities requires a scaling factor dependent on the average backscattering cross section (target strength [TS]) of the fish or zooplankton and physical parameters of the hydroacoustic hardware. Species identification and size distribution were obtained from net samples, and appropriate TS's were then selected from the literature. Pacific herring and capelin TS's were derived from in situ measurements (Halldorsson and Reynisson 1984). Euphausiid TS's were based on in situ measurements (Beamish 1971) and on measurements of preserved euphausiids (Greenlaw 1977). Juvenile walleye pollock (Theragra chalcogramma) TS's were estimated from tank measurements of 5-7 cm cod by Nakken and Olsen (1977).

The 1984 whale prey data were collected at the following settings: 222.0 dB transmit power, -138.7 dB or -132.7 dB receiver gain, 2 kHz bandwidth, 0.7 millisecond pulse width, and 0.5 second pulse rate. The echo sounder automatically compensated for propagation and absorption losses that occur with depth. The echo sounder and transducer were calibrated before and after the study, and no changes in the system's parameters were detected.

Depth intervals and sequence lengths for collecting absolute densities depended on the distribution of the prey. Depth intervals within a prey layer were either 1 or 5 m, and sequence lengths were either 25 seconds (50 pulses) or 50 seconds (100 pulses). Absolute densities are presented as either g/m^3 for a 1 m depth interval or g/m2 for the summation of prey under a square meter surface area.

Sampling

Acoustic targets of fish and micronekton were sampled with nets or sport fishing tackle. Fish were sampled with a 6.0 m x 6.0 m opening Marinovich pelagic-fish trawl consisting of 3.8 cm mesh net and a 0.6 cm mesh cod-end liner. A Simrad net sounder was used to position the trawl at specific depths and monitor acoustic targets entering the trawl mouth. Sport fishing tackle was used to indirectly sample fish that could not be captured with nets; predator fish were hooked in schools of whale prey and their stomachs examined for prey identification. Fish samples were weighed and measured immediately after capture. Micronekton, consisting mainly of euphausiids, was sampled with a 1.8 m opening Isaacs-Kidd midwater trawl (Aron 1962). A Pacific Digital telemetry system was used to position the trawl into micronekton layers that were visible on the chart recorder. Micronekton samples were preserved in a solution of 5-10% formaldehyde in seawater, and processed in the laboratory. Processing included obtaining total displacement volumes and determining the number and size distribution of the predominant invertebrates.

Zooplankton and chlorophyll samples were obtained in conjunction with salinity, temperature, and depth profiles at oceanographic stations. Zooplankton were sampled with a 1 m^2 opening Tucker trawl (Davies and Barham 1969) equipped with three opening and closing 0.5 mm mesh nets. Samples were preserved in a solution of 5-10% formaldehyde in seawater. Water samples were collected from near surface to 50 m depth with Nisken bottles. These samples were poured through 0.45 m HA Millipore filters and processed according to the methods of Strickland and Parsons (1968) to calculate pigment and chlorophyll concentrations. An InterOceans 513D multiparameter probe with a 550A analog recorder was used to obtain profiles of salinity, temperature, and depth.

Whale Identifications

Humpback whales were counted, and were individually identified from photographs of the ventral surface of the whale flukes. Black and white fluke photographs were taken with a 35 mm camera equipped with a.motor drive and 300 mm lens. Identification of individual whales was possible because of the uniqueness of the coloration, shape, and scarring pattern on the ventral side of the flukes (Katona et al. 1979).

RESULTS

Feeding and Movement Observations

Glacier Bay

Twenty-five humpback whales were identified inside Glacier Bay during the spring and summer of 1984 (Perry et al. 1985). Twenty whales were adults and included 9 of the 18 historically best documented whales in Glacier Bay from 1973,to 1980 by Jurasz and Palmer (1981). Nineteen of the '25 humpback whales were encountered during 19 days of whale prey research in' Glacier Bay between 28 July and 12 September.

The most common type of humpback whale feeding observed in Glacier Bay from 1982 to 1984 was on nearshore fish schools in the lower part of the bay. In 1984, the whale feeding covered larger areas and prey diversity increased compared to 1982 and 1983. The majority of feeding in 1984 occurred in shallow waters on fish, mainly capelin and walleye pollock. Two whales were feeding on young-of-the-year walleye pollock on 30 July off west Sturgess Island (Fig. 2A), and a single whale was feeding on pollock on 5 August off South Marble Island (Fig. 2B). Densities of pollock were estimated at 9.4 and 35.2 g/m^3 (Table 1). Capelin were identified as prey for four whales on 19 August at north Strawberry Island-(Fig. 3A) and for three whales on 21 August at east Willoughby Island (Fig. 38). Densities of capelin were estimated at 4.0 and 33.6 g/m^3 (Table 1). Near-surface feeding on scattered fish schools

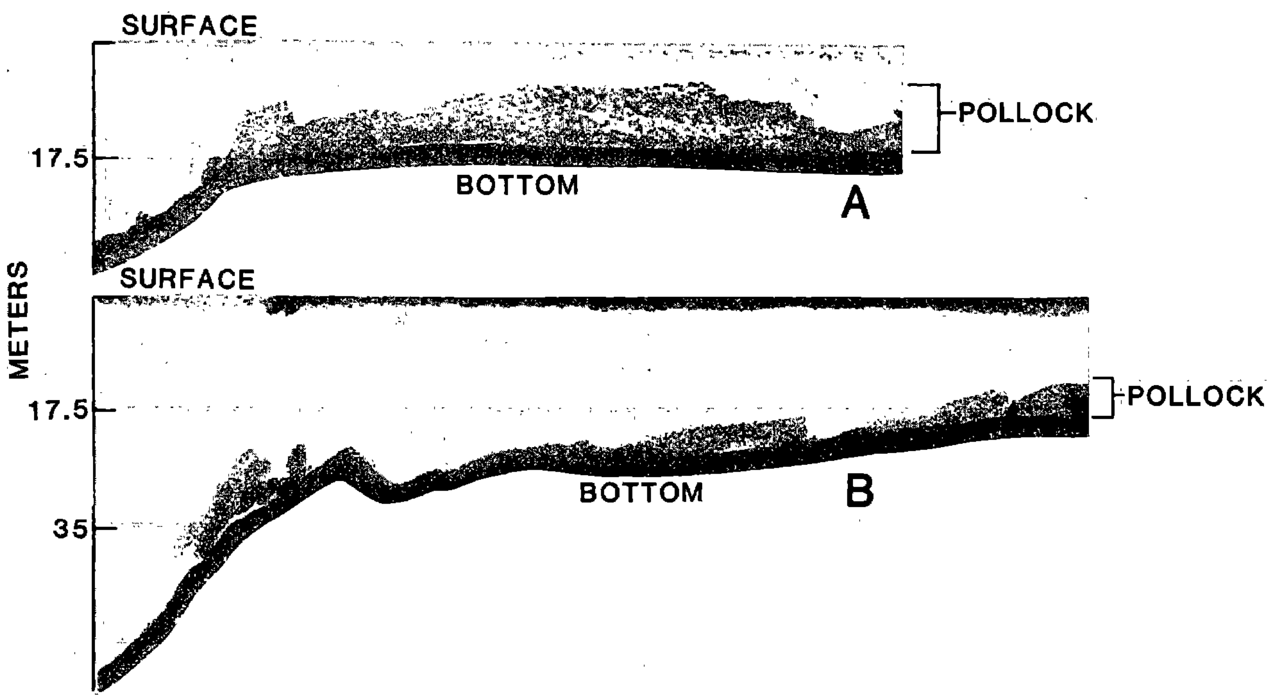

Figure 2.--Echosoundings of humpback whale prey (O+ walleye pollock) in Glacier Bay at A) west Sturgess Island on 30 July 1984, and B) southwest Leland Island on 5 August 1984.

Table 1.--Density estimates of prey at humpback whale feeding sites in southeastern Alaska in 1984.

Area	Date	Prey type	Average length/weight (mm) (g)	Depth of forage (m)	Prey density[a] g/m²	Prey density[a] g/m³	Prey density[a] Number of targets/m³
Glacier Bay:							
West Sturgess Is.	30 Jul	Pollock	74/3.0	10-16	26.0	9.4	3.0
Tlingit Pt.	4 Aug	Euphausiids	19/.02[b]	40-50	29.3	3.1	51.7
South Marble Is.	5 Aug	Pollock	74/3.0	24-29	102.2	35.2	11.4
North Strawberry Is.	19 Aug	Capelin	100/5.0[b]	25-55	60.0	4.0	0.8
East Willoughby Is.	21 Aug	Capelin	100/5.0	60-80	483.5	33.6	6.7
Icy Strait:							
Point Adolphus	27 Jul	Herring	205/100.0	25-50	1391.6	143.3	1.4
Point Adolphus	6 Aug	Herring	205/100.0	35-60	4980.5	410.9	4.1
Point Adolphus	24 Aug	Herring	205/100.0	30-60	1130.5	97.1	1.0
South Lemesurier Is.	3 Aug	Pollock	74/3.0	5-10	204.0	12.4	4.0
Stephens Passage:							
Doty Cove	5 Sep	Euphausiids	17/.04	75-135	145.0	6.2	155.0
Twin Point	6 Sep	Euphausiids	13/.02	75-100	46.7	2.8	140.0
Point Glass	6 Sep	Euphausiids	13/.02[b]	100-125	72.4	4.6	230.0
Doty Cove	15 Sep	Euphausiids	12/.02	60-100	45.6	1.9	95.0
Point Glass	15 Sep	Euphausiids	12/.02[b]	75-105	59.0	3.6	180.0
Twin Point	15 Sep	Euphausiids	12/.02[b]	70-135	218.0	6.1	305.0
Seymour Canal	15 Aug	Euphausiids	15/.03[b]	90-115	67.5	6.8	226.6

Table 1.--Continued.

Area	Date	Prey type	Average length/weight (mm) (g)	Depth of forage (m)	Prey density[a] g/m²	Prey density[a] g/m³	Prey density[a] Number of targets/m³
Frederick Sound:							
Sail Island	15 Aug	Euphausiids	15/ .03[b]	5-20	282.8	31.0	1,033.3
Five Finger	15 Aug	Euphausiids	15/ .03	90-100	79.5	11.9	396.7
Five Finger	7 Sep	Pollock	74/3.0[b]	95-125	214.5	13.8	4.6
Chatham Strait:							
Port Malmsbury	16 Aug	Euphausiids	15/.03[b]	145-175	183.5	10.7	356.7

[a] Conversion factors:

	Pollock	Euphausiids	Capelin	Herring
Target strength dB/g	-60.0	- 68.0	-65.9	-66.4
Target number/g	0.3	50.0	0.125	0.01

[b] Prey types estimated from sonar chart recordings and prey sizes estimated from samples taken in adjacent areas.

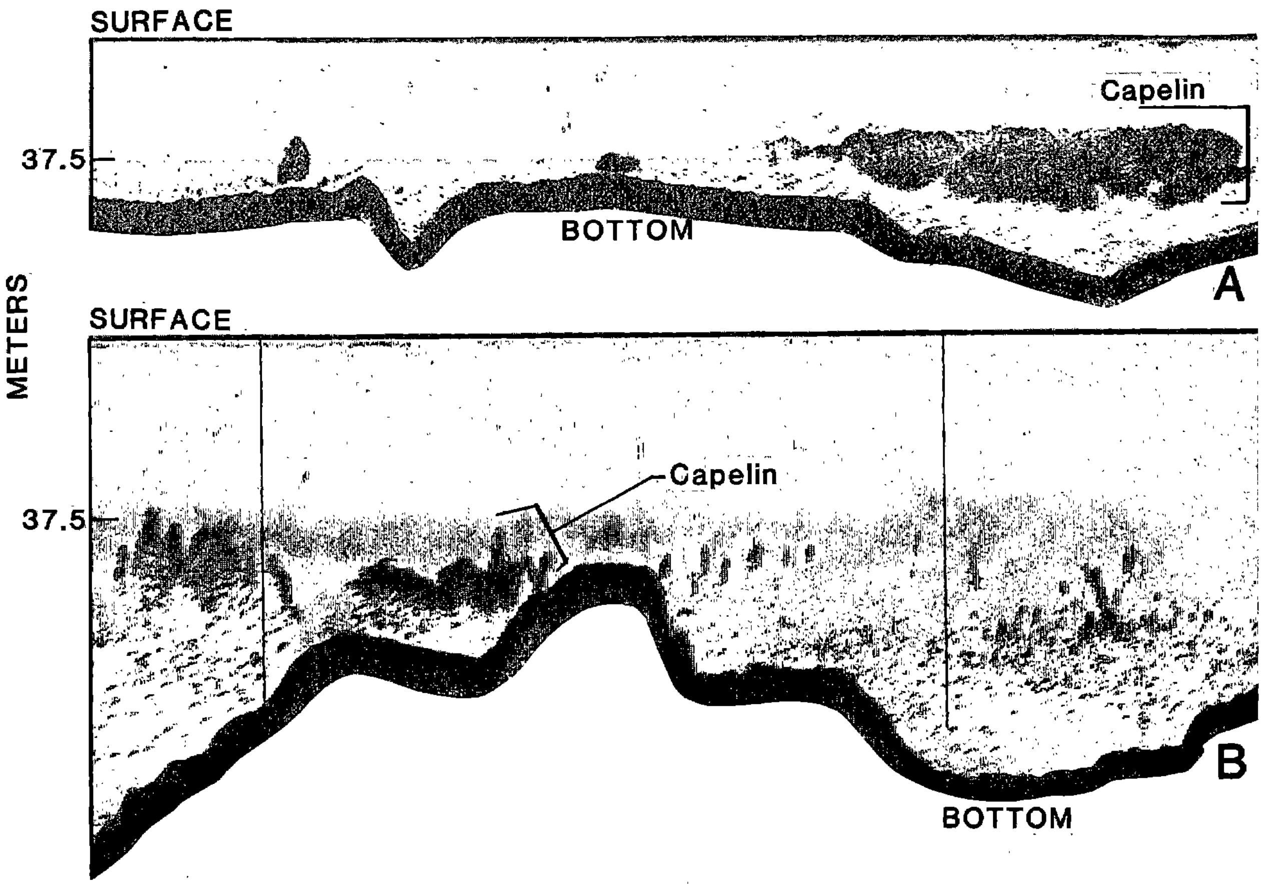

Figure 3.--Echosoundings of humpback whale prey (capelin) in Glacier Bay at A) north Strawberry Island on 19 August 1984 and B) east Willoughby Island on 21 August 1984.

was observed on several occasions in Sitakaday Narrows. Net sampling in these areas produced a mixture of pollock, capelin, Pacific herring, and Pacific sand lance, Ammodytes hexapterus. Prior to our arrival into Glacier Bay, NPS personnel reported considerable whale feeding in the mouth of Muir Inlet during the last half of June and early July. They reported that extensive capelin schools could be seen near the surface where the whales were feeding.

Euphausiid feeding by humpback whales was not observed in Glacier .: Bay in 1982 or 1983. In 1984, we observed Glacier Bay whales feeding on euphausiids on only two occasions: Two whales. were feeding on a subsurface euphausiid layer off Tlingit Point on 4 August (Fig. 4) at densities estimated at 3.1 g/m3 (Table.l), and two whales were surface feeding on euphausiids at the mouth of the West Arm on 23 August.

We documented considerable local movement of Glacier Bay humpback whales in 1984. We identified nine whales that moved between Glacier Bay and Icy Strait, and six of these moved between areas more than once. The most extensive movement between the areas was by two of the historically best documented whales that returned annually to Glacier Bay prior to 1978 (Jurasz and Palmer 1981). Five of the whales identified in Glacier Bay in July were later identified in Stephens Passage in August and September.

Icy Strait

Humpback whales were consistently found in Icy Strait, subsurface feeding on Pacific herring during the 1982 and 1983 whale prey studies (Krieger and Wing 1984). During 1984, we encountered 20 individual humpback whales during eight censuses in Icy Strait. Most of the whales

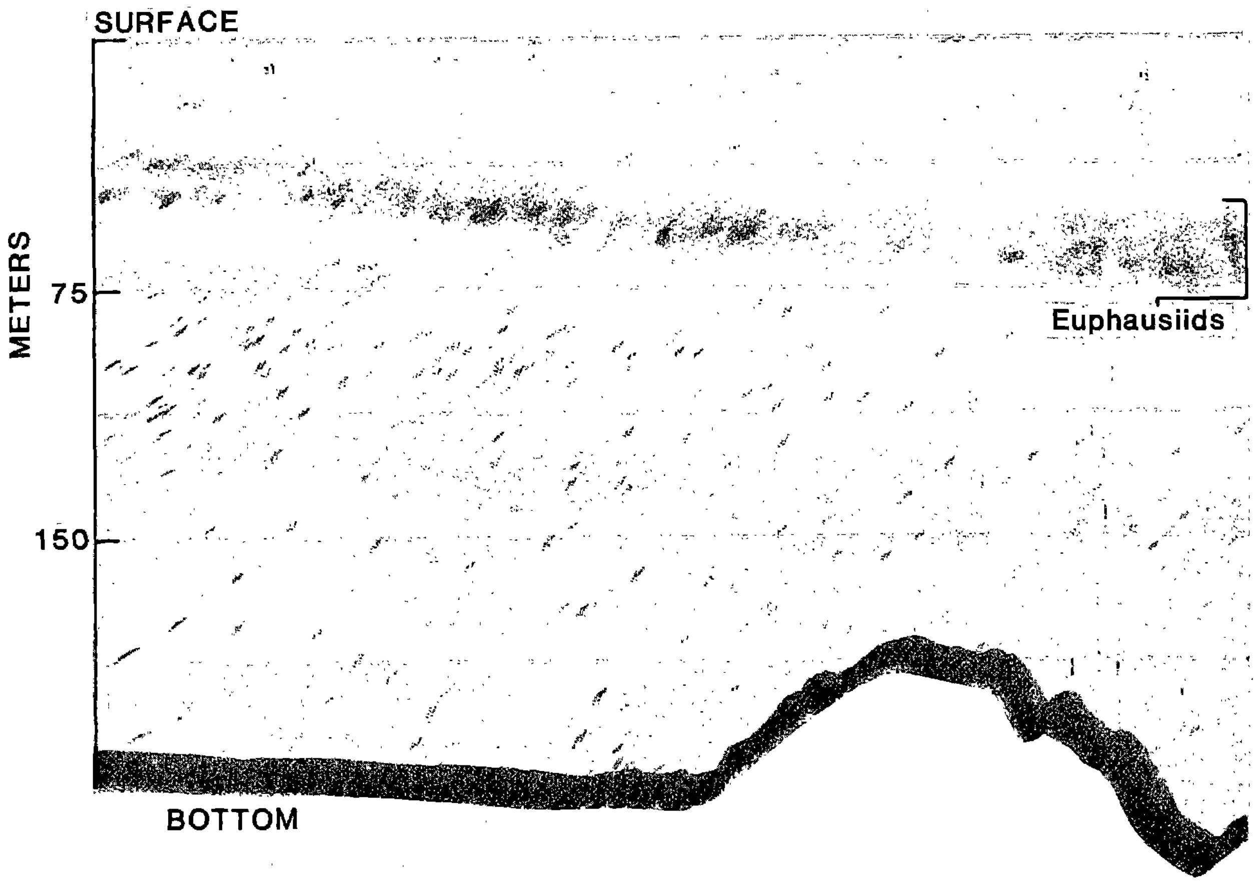

Figure 4.--Echosounding of humpback whale prey (euphausiids) in Glacier Bay near Tlingit Point on 4 August 1984.

were located at Point Adolphus or in South Passage between Quartz Point and southeast Lemesurier Island. These whales were feeding on either Pacific herring or young-of-the-year pollock.

We identified 14 individual whales subsurface feeding on Pacific herring at Point Adolphus. Density estimates of Pacific herring for three different days were 143.3, 410.9, and 97.1 g/m^3 (Table 1). The highest square meter Pacific herring density was 4,980.5 g/m* for a school extending between 35 and 60 m (Fig. 5A). Six of the Point Adolphus whales were also identified in Glacier Bay, and three were identified in Stephens Passage.

South Passage was not a major humpback whale feeding area in 1982 and 1983. In South Passage in 1984, we encountered nine whales located between Quartz Point and southeast Lemesurier Island. These whales were usually subsurface feeding next to shore on schools of young pollock (Fig. 58). A density estimate of the pollock was 12.4 g/m^3 and 204.0 g/m* for a school extending 5-10 m (Table 1). Six of the South Passage whales were identified in Glacier Bay, three at Point Adolphus, and two in Stephens Passage.

Northern Chatham Strait

Sixteen whales feeding on fish were identified in northern Chatham Strait during three surveys. A pod of.whales was observed on each of the three surveys, with some of the whales common to all pods.

On 26 July, five adults and a calf were group surface feeding along a reef near Whitewater Bay. On 18 August, seven adults and a calf were group surface feeding in Tenakee Inlet located 65 km northwest of Whitewater Bay. These whales lunged 10 times through feed during an

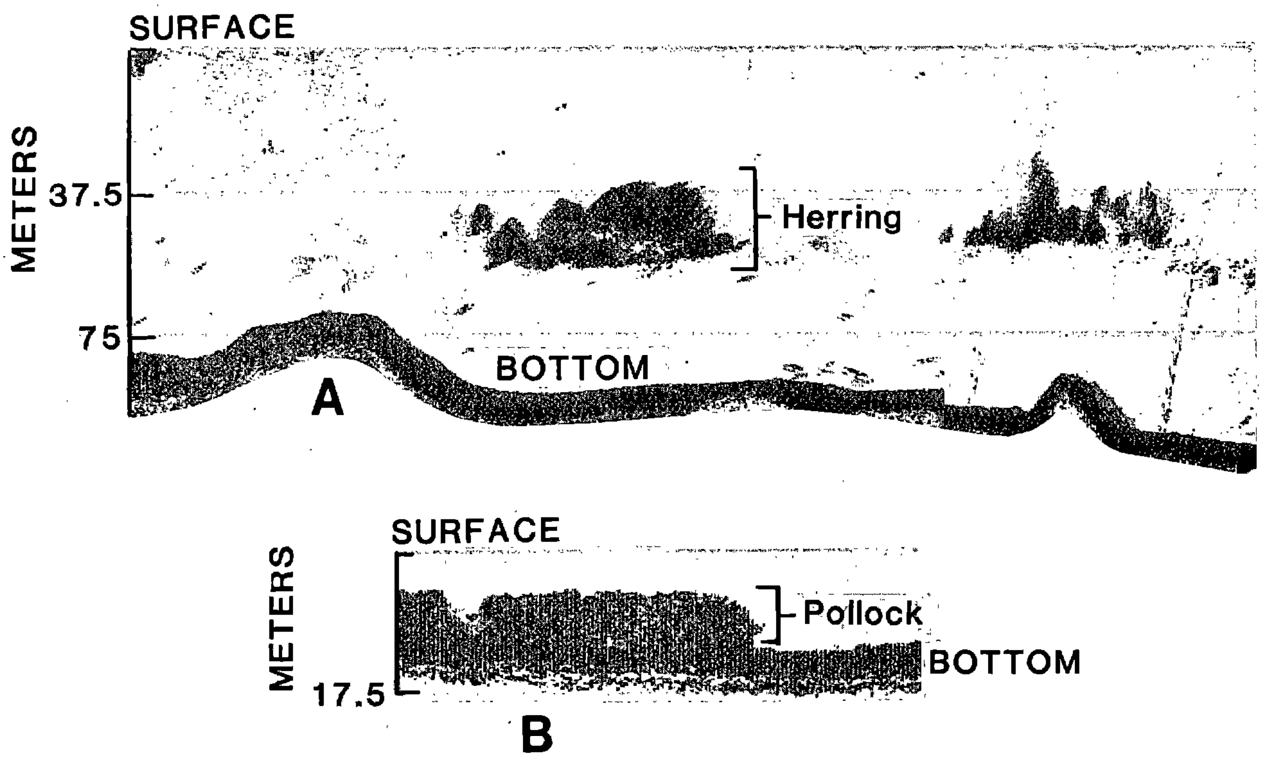

Figure 5.--Echosoundings of humpback whale prey in Icy Strait composed of A) Pacific herring and B) age 0+ walleye pollock.

hour-long observation period. On 13 September, seven adults and a calf were group lunge feeding at the mouth of Peril Strait, which is 48 km south of Tenakee Inlet. The prey were in water too shallow to be assessed or sampled but, based on chart recordings of their schooling patterns, were probably Pacific herring.

Five adults were common to at least two of the three groups, and two adults and a calf were common to all three of the groups in northern Chatham Strait. Five whales from a similar lunge-feeding group of 10 whales observed in Tenakee Inlet during 1981 (Baker and Herman 1984) were also found in at least one of the three groups observed during 1984. The animal thought to be the leader of this cooperative behavior was found in three lunge-feeding groups during 1981 and all three of the lunge-feeding groups during 1984. Two of the northern Chatham Strait whales were later seen in Stephens Passage.

Southern Chatham Strait

Over 30 humpback whales were reported in southern Chatham Strait in late July by the captain of the research vessel John N. Cobb. We made a Iiday survey of the area in mid-August and identified 22 whales. On 16 August, a group of at least 21 whales was subsurface feeding on a deep scattering layer of euphausiids, 2-4 km off shore of Port Malmsbury (Fig. 6). The whales were generally in pods of three or four, and dive times averaged about 10 minutes. A feces sample from one of the whales consisted of euphausiid remains. The highest density of the euphausiid layer, which extended 145-175 m, was 10.7 g/m^3 and 183.5 g/m2.

On 17 August, a pair of whales was surface lunge feeding 15 km north of Port Malmsbury. Their prey were too close to the surface to be recorded with hydroacoustic equipment.

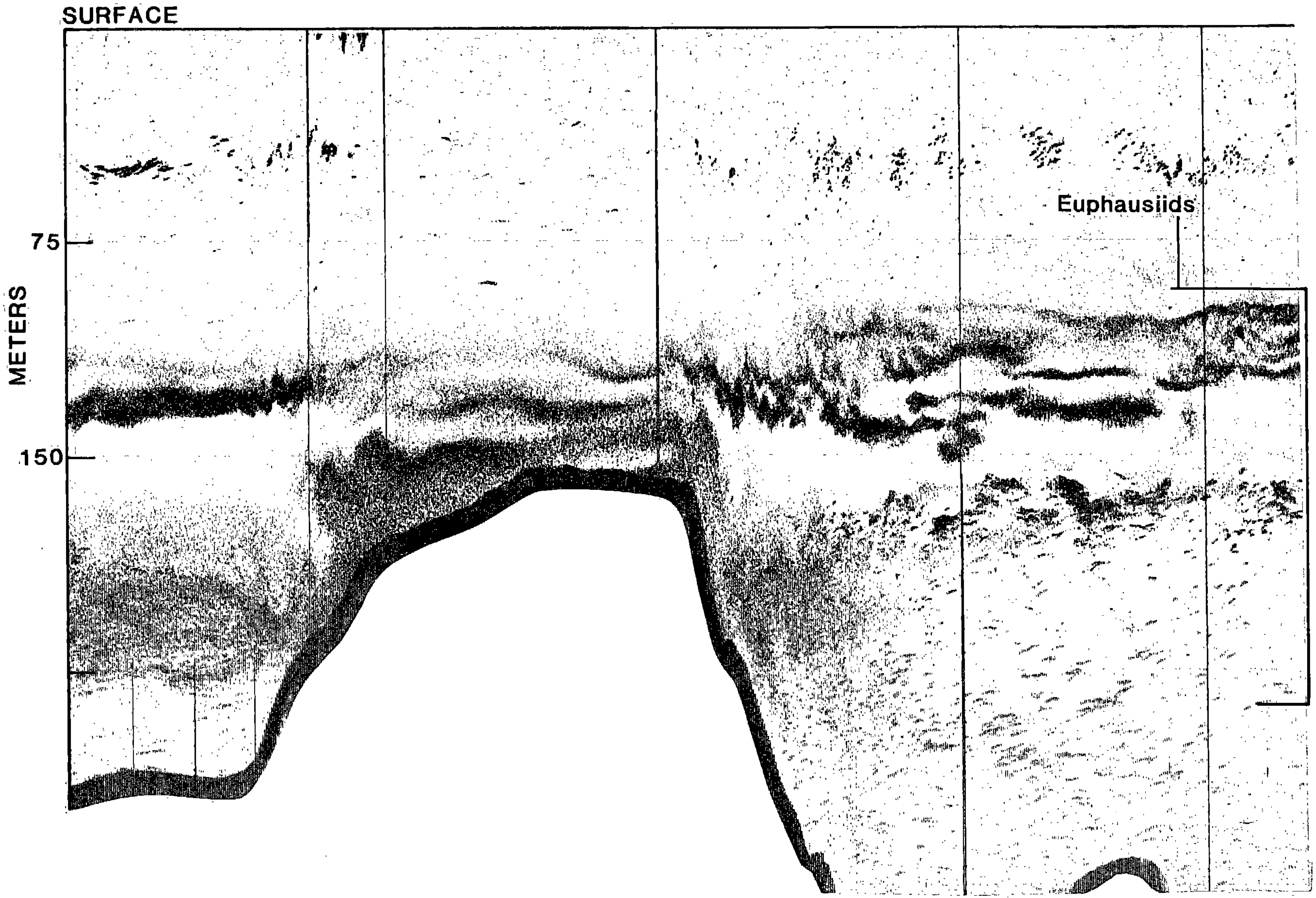

Figure 6.--Echosoundings of humpback whale prey (euphausiids) in southern Chatham Strait on 5 August 1984.

The southern Chatham Strait whales were not identified in other areas of southeastern Alaska. One of the whales, however, was photographed in Prince William Sound in 1977 and 1980 (Baker et al. 1985).

Frederick Sound

Fifty-three humpback whales, feeding mainly on euphausiids, were identified in Frederick Sound during 5 days of surveying. A large concentration of feeding whales was encountered near Five Finger Island on 25 July. These whales used three different types of feeding behavior to capture euphausiids: 1) subsurface- feeding with dive times of 3-5 minutes, 2) near-surface, bubble-net feeding in which the whales concentrate the prey by blowing a ring of bubbles around the prey and then lunging up through the ring, and 3) surface, lateral lunge feeding. On 15 August, at least 24 whales were found subsurface feeding and bubble-net feeding on euphausiids from Sail Island to south of Five Finger Island. Euphausiids were distributed throughout the upper water column (Fig. 7) with high densities of 31.0 g/m^3 recorded near bubble netting at Sail Island (Table 1). On 7 September, at least eight whales were subsurface feeding on a school of fish east of Five Finger Island (Fig. 8). The fish could not be sampled because of the rough bottom and strong currents but, based on the schooling pattern and intensity of the echo returns, were probably juvenile pollock. A density of 13.8 g/m^3 (214.5 g/m*) was estimated for this school. Eight whales were observed later in the day dispersed north of Sail Island toward McDonald Rock. Frederick Sound was last searched on 14 September, and a group of four whales were lunging through surface feed about 6 km east of Spruce Island. Surface net tows confirmed juvenile euphausiids in the patches.

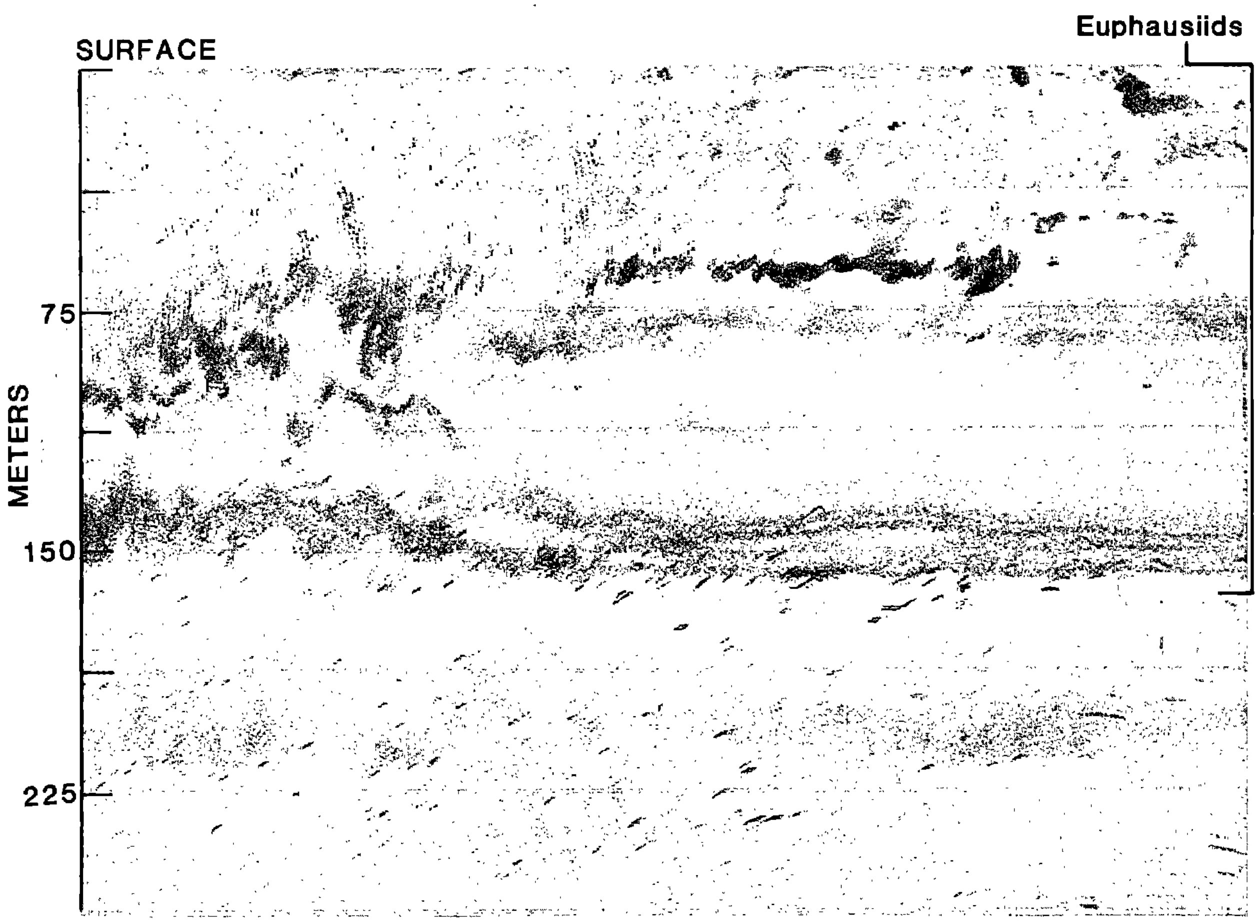

Figure 7.--Echosounding of humpback whale prey (euphausiids) in Frederick Sound on 4 August 1984.

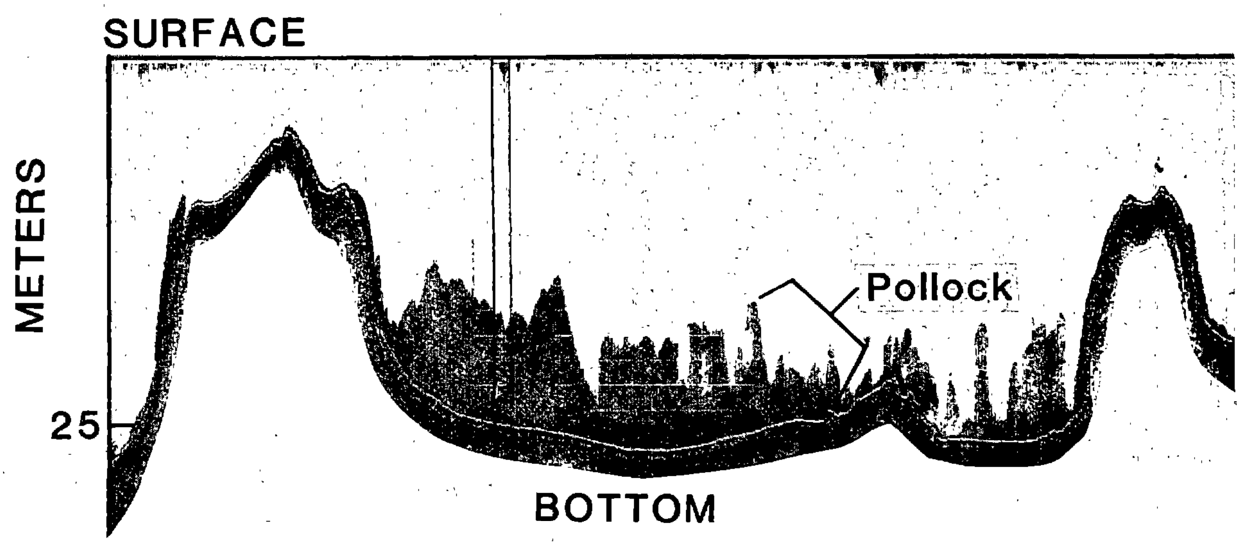

Figure 8.--Echosounding of humpback whale prey (assumed to be age 0+ walleye pollock) in Frederick Sound on 7 September 1984.

No whales from other areas of southeastern Alaska were seen in Frederick Sound, but 12 Frederick Sound whales were later identified in Stephens Passage. One of the whales photographed in Frederick Sound on 15 August was previously photographed in Prince William Sound during 1980 (Baker et al. 1985).

Stephens Passage

Ninety humpback whales were identified in Stephens Passage in 1984. These whales were identified in 5 days of surveying, which included four different cruise periods. Most of the whales were feeding on dense layers of subsurface euphausiids.

Only three whales were observed in Stephens Passage during our. first cruise in late July. On 14 August, three single whales were found subsurface feeding near the mouth of Port Snettisham, and three groups of three whales were near the mouth of Holkam Bay. Dive times of all whales were consistently 4-5 minutes on euphausiid layers at 60-100 m. Euphausiid remains were observed in fecal matter from one of the whales. An additional two whales were feeding on a euphausiid layer extending between 90 and 115 m near Point Hugh in Seymour Canal (Fig. 9). Density of this layer was estimated at 6.8 g/m^3 and 67.5 g/m* (Table 1).

Most whale sightings in Stephens Passage were during September. On 5 September, 25 whales were identified in Doty Cove. An additional 25 whales were identified the following day in southern Stephens Passage. The Doty Cove whales were generally in groups of three to four, and their dive times were 8-10 minutes on a euphausiid layer that extended between 75 and 135 m (Fig. 10). Densities of the layer were 6.2 g/m3 and 145.0 g/m* (Table 1). Approximately 10 of the whales ir southern Stephens Passage were feeding on a euphausiid layer near Twin Point.

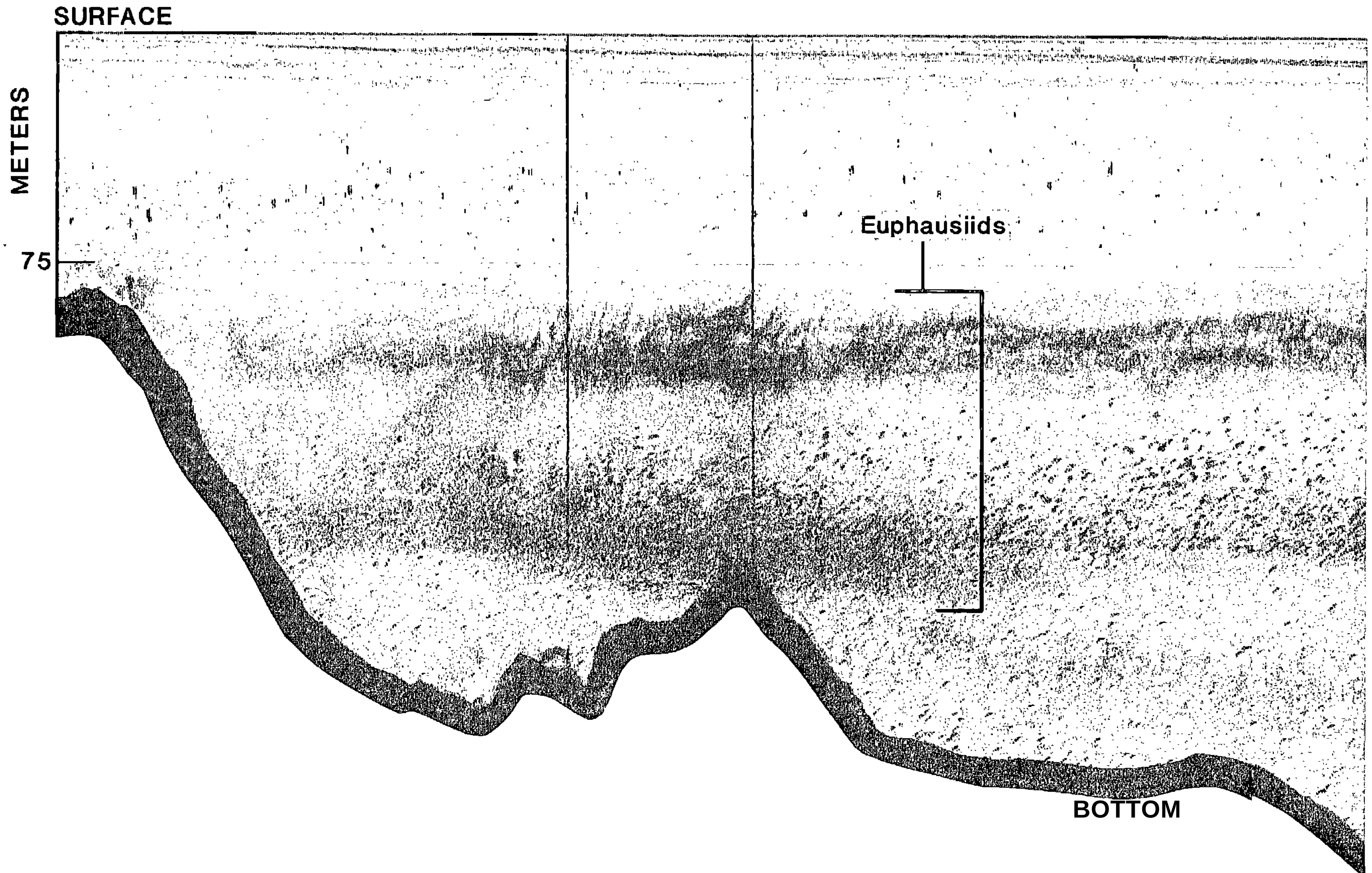

Figure 9.--Echosounding of humpback whale prey (euphausiids) in Seymour Canal on 5 August 1984.

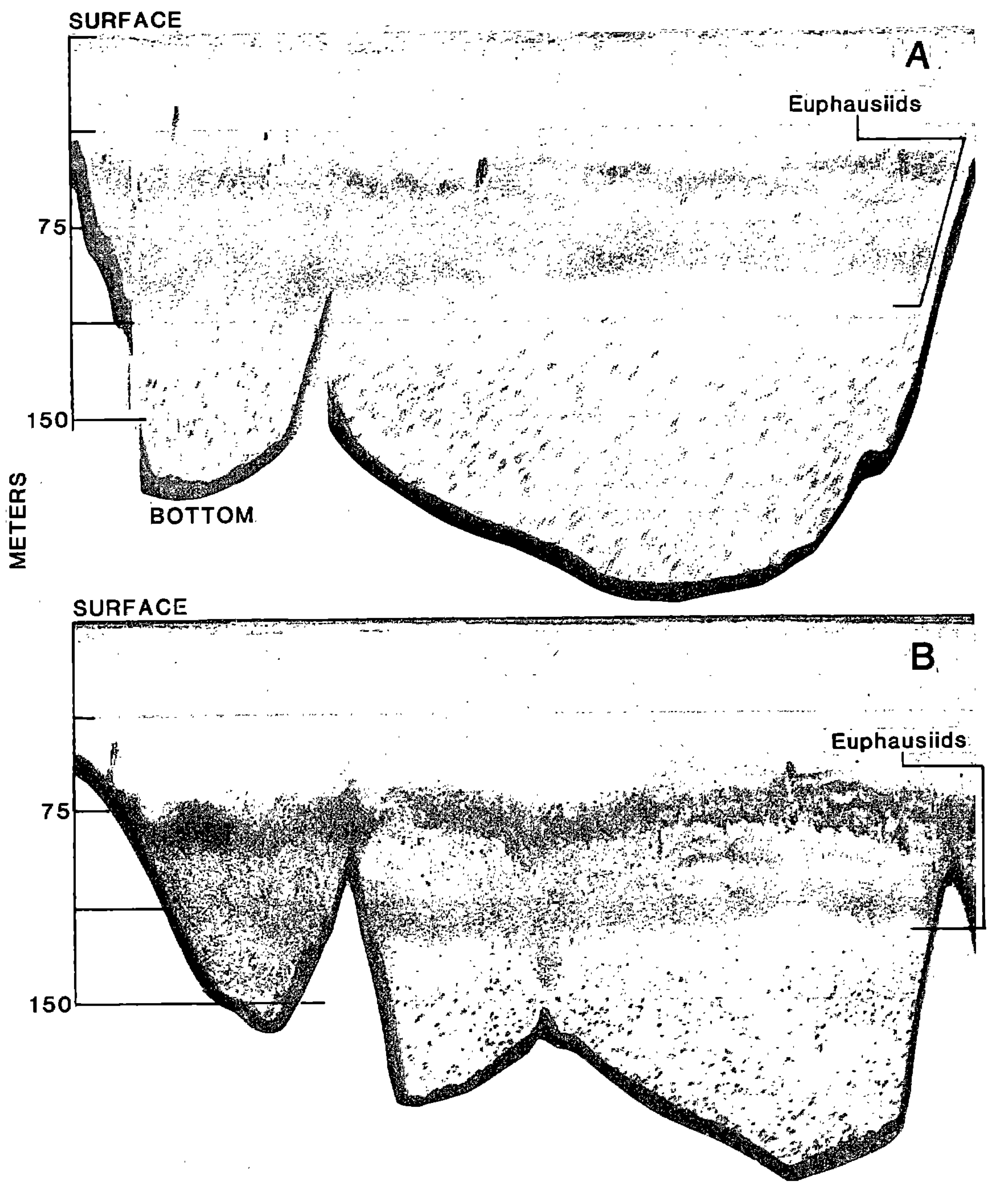

Figure 10.--Echosoundings of humpback whale prey (euphausiids) in Doty Cove, Stephens Passage, on A) 24 July 1984 prior to arrival of whales and B) 5 September 1984 when whales were feeding.

This layer extended 75-100 m at densities of 2.8 g/m^3 and 46.7 g/m* (Table 1). Three whales were feeding on euphausiids at Point Glass on a layer extending 100-125 m at densities of 4.6 g/m3 and 72.4 g/m* (Table 1). Recordings of this layer (Fig. 1.1) also show profiles of diving whales. Most of the other whales were dispersed on the east side of Stephens Passage in the Holkam Bay area, including a single whale that was bubble-net feeding. Thirty-one whales were identified in Stephens Passage on 15 September. Nine of the whales were feeding on euphausiids in the southern end of Doty Cove near Grand Island. This layer extended 60-100 m at densities of 1.9 g/m^3 and 45.6 g/m*. Three whales were feeding at Point Glass, on euphausiids extending 75-105 m at densities of 3.6 g/m^3. and 59.0 g/m* (Fig. 12A). Most of, the other whales 'were diving 6-8 minutes just south of Twin Point on a euphausiid layer extending 70-135 m at densities of 6.1 g/m3 and 218.0 g/m* (Fig. 12B).

A concentration of over 20 humpback whales was found in Doty Cove in early September 1983, feeding on dense layers of euphausiids. In 1984, the number of whales and density of euphausiids were assessed during each of the four trips through the area. These surveys indicate that the number of whales increased with the density of prey: euphausiid densities increased sixfold from late July (Fig. 10A) to early September (Fig. 1OB) and then decreased by a factor of three by mid-September (Table 2). Whale numbers increased from 0 to 25 from late July to early September and then decreased to 9 by mid-September (Table 2).

Area Surveys

Hydroacoustic surveys were continued in Glacier Bay and Fredrick Sound in 1984 along transects established in 1982 and 1983 to monitor

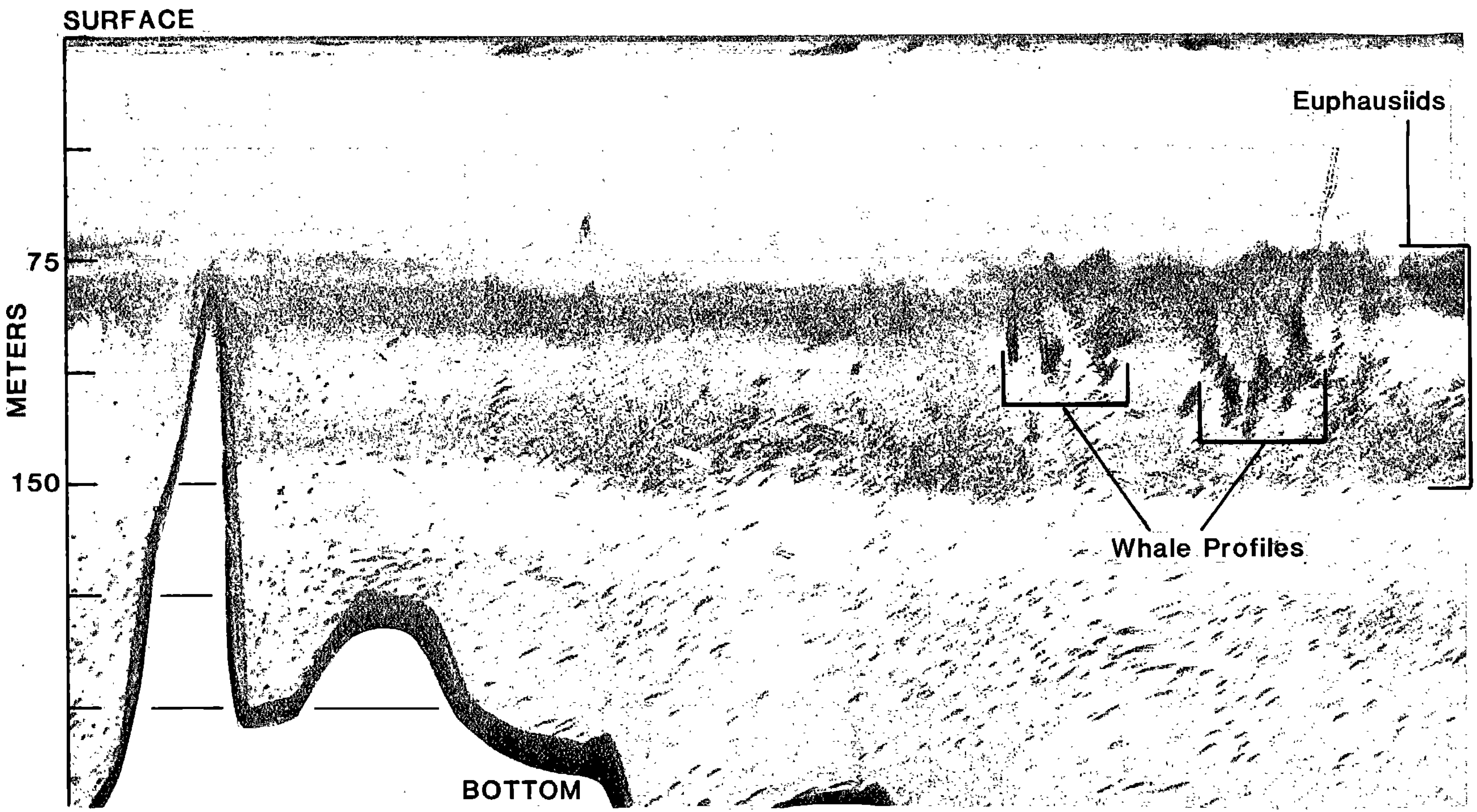

Figure 11.--Echosounding of humpback whale prey (euphausiids) with profiles of whales in the prey at Twin Point, Stephens Passage, on 6 September 1984.

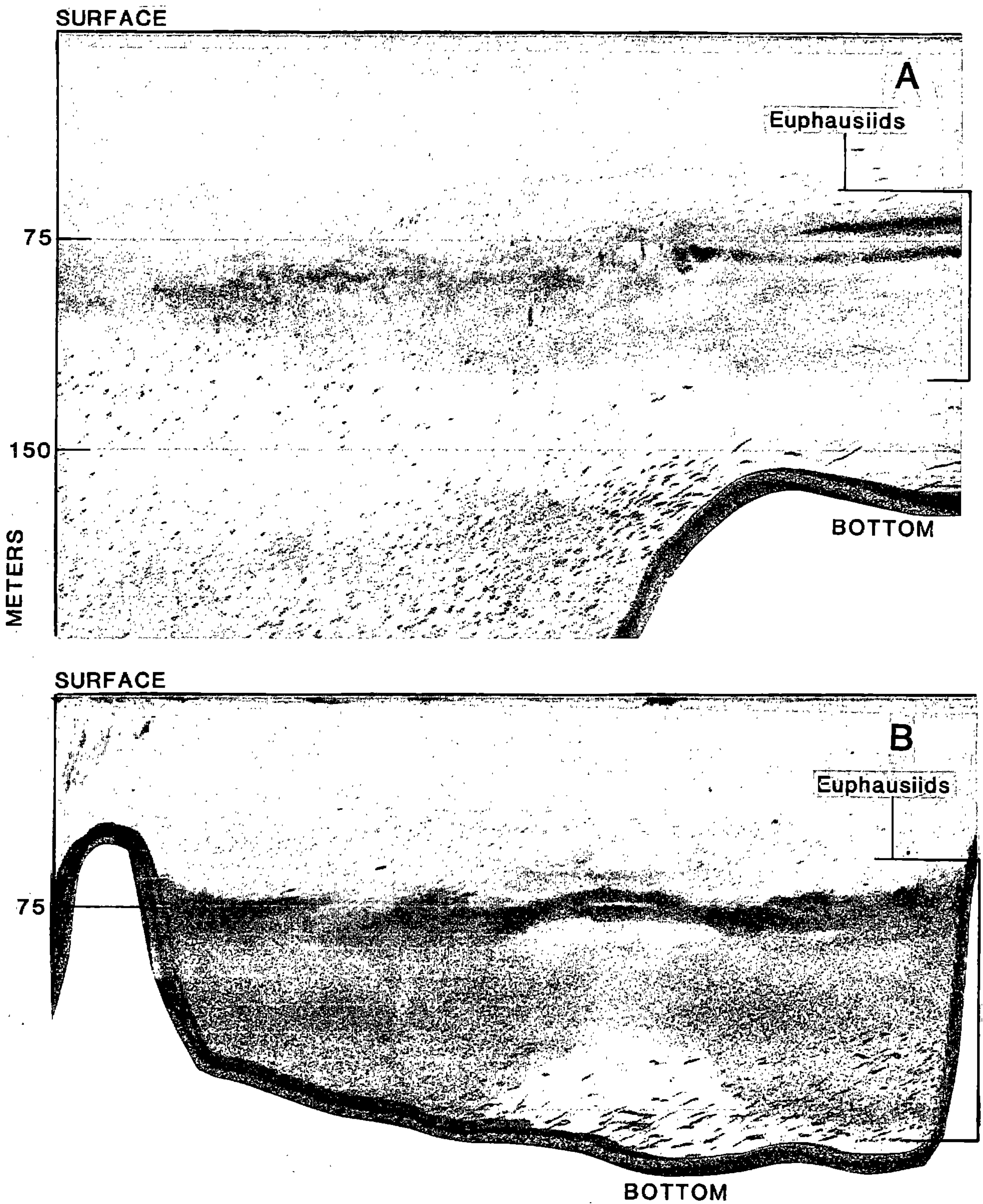

Figure 12.--Echosoundings of humpback whale prey (euphausiids) at A) Point Glass, Stephens Passage, and B) 'Twin Point, Stephens Passage, on 15 September 1984.

Table 2.--Density estimates of euphausiids at whale feeding sites in Doty Cove, southeastern Alaska, in 1984.

Date	Number of whales	Depth of prey (m)	Average length/weight (mm) (g)	Prey density g/m²	Prey density g/m³	Prey density Number of targets/m³
24 Jul	0	50-105	15/.02	22.8	0.9	45.0
14 Aug	0	80-115	21/.08	24.2	1.8	22.5
5 Sep	25	85-135	17/.04	145.0	6.2	155.0
15 Sep	9	60-100	12/.02	45.6	1.9	95.0

annual and seasonal fluctuations in prey densities. The relative (back scattering) densities from these surveys include the reflected energy from all fish and zooplankton targets 5 m below the surface to a maximum depth of 200 m.

Glacier Bay

We conducted hydroacoustic surveys on seven different days in lower and mid-Glacier' Bay. Five surveys were from Rush Point to Tidal Inlet (five transects covering 52 km), and two surveys were from Rush Point to Geikie Inlet (four transects covering 35 km). All of the area backscattering densities and most of the transect densities were higher in 1984 than in 1982 and 1983 (Table 3). The highest backscattering densities for 1984 occurred in late August and September (Table 3 and Figs. 13A-E).

In 1982 and 1983, the lower part of Glacier Bay (Transects 1 and 2) was essentially devoid of prey except for single fish targets (Krieger and Wing 1984). In 1984, numerous schools of small fish were found in this area with the heaviest concentrations occurring in late August (Fig. 13A). Increased prey densities also occurred in mid-Glacier Bay due to increases in both fish (mainly young pollock) and euphausiids. Schools of pollock were not recorded in 1982 or 1983 but were common throughout 1984 with highest densities occurring near Geikie Inlet (Fig. 13D). Euphausiid densities in Glacier Bay were also higher in 1984 compared to 1982 and 1983. The high density was 1.9 g/m^3 recorded on 29 August 1984 compared to the highest prior density of 0.1 g/m^3 on 12 September 1983. In Glacier Bay, most of the humpback whale feeding occurred in Bartlett Cove during 1982 (Baker et al. 1983). These whales fed on capelin which we hydroacoustically recorded and sampled with a

Table 3.--Relative density estimates (backscatter/m^2) of fish and zooplankton during hydroacoustic transects in Glacier Bay, southeastern Alaska, surveyed in 1982, 1983, and 1984.

Area	12 Aug 1982	20 Aug 1982	5 Aug 1983	25 Aug 1983	12 Sep 1983	28 Jul 1984	7 Aug 1984	19 Aug 1984	23 Aug 1984	29 Aug 1984	31 Aug 1984	11 Sep 1984
Transect 1:												
Rush Point Strawberry Is.	0.3	0.2	1.2	0.4	1.0	1.9	1.7	1.8	1.4	20.6	3.4	3.1
Transect 2:												
Strawberry Is. Willoughby Is.	1.6	0.6	1.6	1.5	2.5	2.6	4.9	4.0	2.0	8.9	4.1	3.0
Transect 3:												
Willoughby Is. Sturgess Is.	4.8	5.7	4.2	3.8	5.6	6.9	7.5	8.7	7.5	10.2	11.5	9.7
Transect 4:												
Sturgess Is. Geikie Inlet	2.4	4.8	4.2	6.0	5.6	11.6	7.7	6.0	5.9	8.7	8.5	15.2
Transect 5:												
Geikie Inlet Tidal Inlet	3.6	3.4	4.5	7.3	9.1	10.9	8.1	9.3		12.3		40.7
Average (weighted by transect lengths)												
Transects 1-5:												
Rush Point Tidal Inlet	3.1	3.5	3.8	4.7	5.4	8.0	7.2	6.7	-	10.8	-	18.8

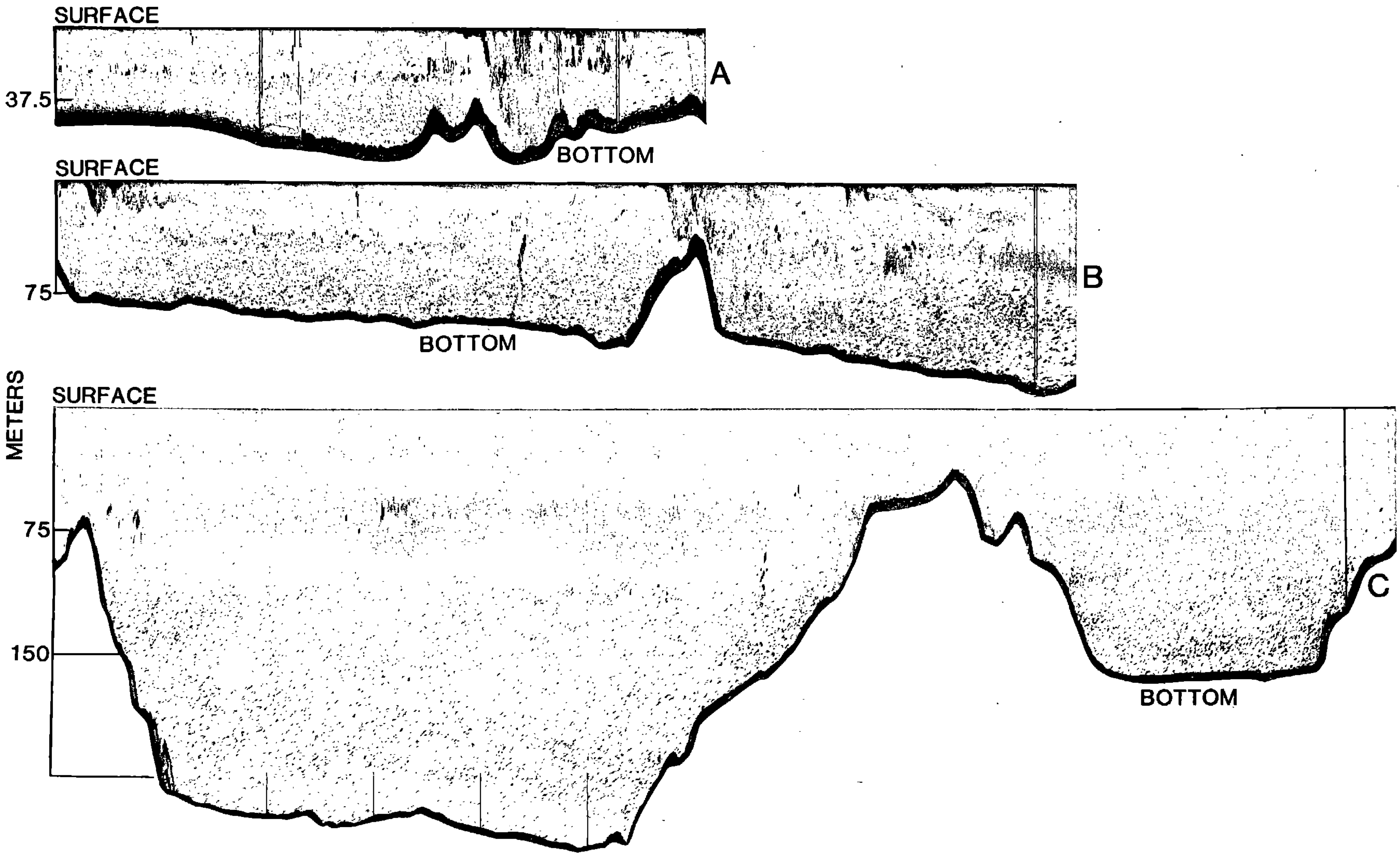

Figure 13.--Echosoundings of the highest prey densities recorded in Glacier Bay during standard transects. Prey were recorded on 29 August 1984 from A) Rush Point to Strawberry Island-transect 1, B) Strawberry Island to Willoughby Island-transect 2, and C) Willoughby Island to Sturgess Island-transect 3.

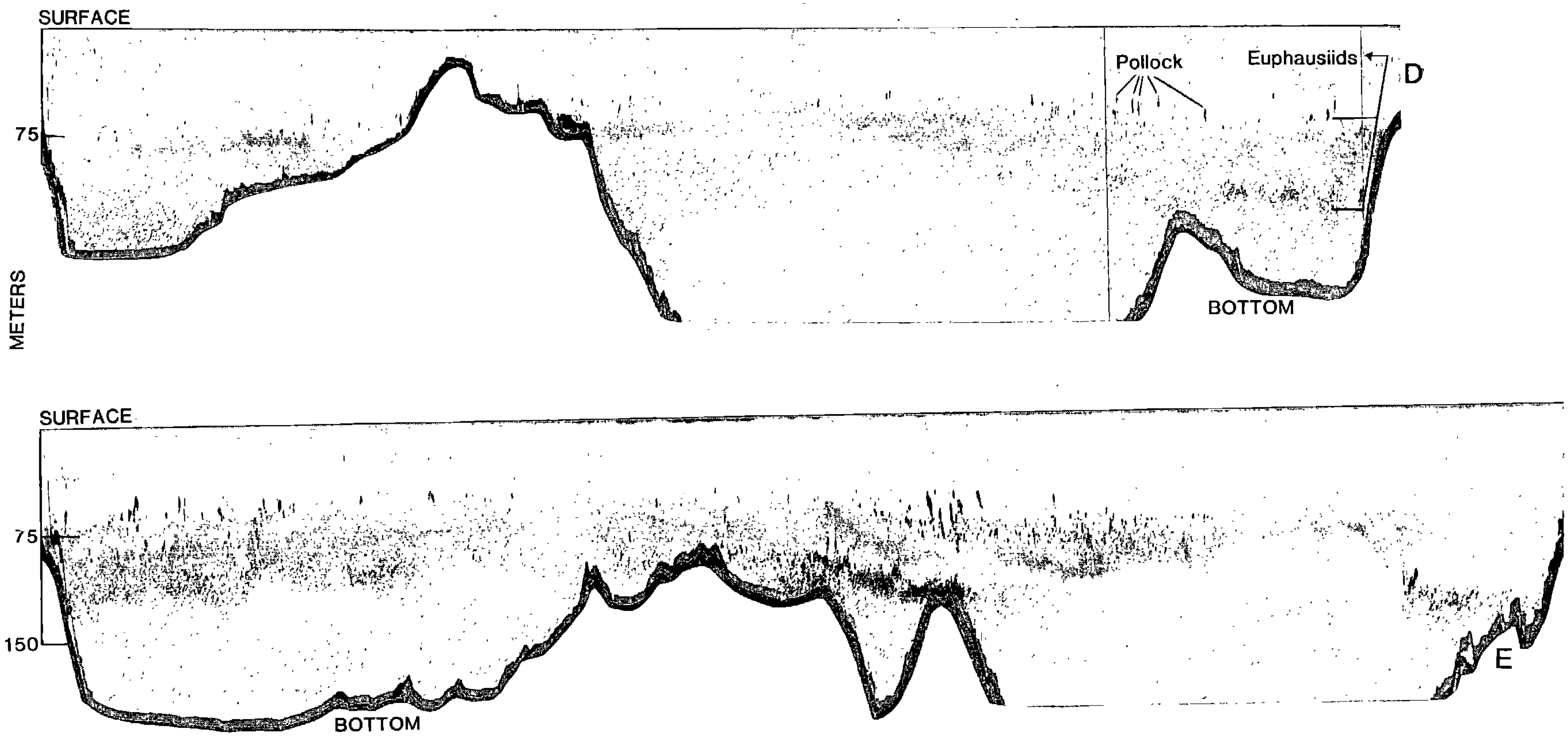

Figure 13.--Continued. Echosoundings of the highest prey densities recorded in Glacier Bay during standard transects. Prey were recorded on 11 September 1984 from D) Sturgess Island to Geikie Inlet and E) Geikie Inlet to Tidal Inlet.

pelagic fish trawl (Wing and Krieger 1983). We conducted numerous hydroacoustic surveys of Bartlett Cove in 1983 and 1984 to monitor whale prey. No capelin schools or other concentrated prey were found in Bartlett Cove during 1983 or 1984, and no whales were documented feeding in the cove.

Frederick Sound

We conducted hydroacoustic surveys,, on four different days in Frederick Sound. Two of the surveys were from Point Hugh to Spruce Island (four transects covering 73 km), and two were from Point Hugh to Entrance Island (one transect covering 27 km). The backscatter density levels and the variations in the densities were similar to those observed in prior years (Table 4). The only noticeable difference was an increase in prey density on 6 September 1984 during Transect 3 from False Point Pybus-Round Rock. This increase was probably caused by young pollock.

Whale Behavior

During our 3 years of whale prey research, we observed a diversity of whale feeding patterns and reactions to vessels that were prey related. This section summarizes the general feeding patterns associated with specific prey and the reactions of whales to our research vessels.

Feeding Patterns

Most of the whale feeding we observed in Glacier Bay was on small schools of fish, mainly capelin and pollock. The main feeding mode was "browsing"; one or two whales would search along the shoreline and stop to feed on small schools of fish. The only long-term concentrated

Table 4.--Backscattering density estimates (backscatter/m^2) from hydroacoustic transects in Stephens Passage-Frederick Sound, southeastern Alaska, surveyed in 1982, 1983, and 1984.

Area	3 Aug 1982	4 Aug 1982	20 Aug 1982	3 Sep 1983	25 Jul 1984	15 Aug 1984	6 Sep 1984	14 Sep 1984
Transect 1:								
Pt. Hugh Entrance Is.	8.9	9.4	15.5	12.0	16.8	7.2	10.9	11.8
Transect 2:								
Entrance Is. False Pt. Pybus	19.8	13.1	9.8	10.5	19.3	---	10.1	---
Transect 3:								
False Pt. Pybus Round Rock	4.9	1.2	2.7	4.5	5.3	---	20.5	---
Transect 4:								
Round Rock Spruce Is.	2.1	2.5	7.6	0.9	2.5	---	2.7	---
Average (weighted by transect lengths)								
Transects 1-4:								
Pt. Hugh Spruce Is.	9.9	8.1	10.5	8.7	13.7	---	11.3	---

feeding we observed was in Bartlett Cove during 1982 when three or more whales exhibited synchronized feeding on capelin schools.

Herring and pollock have been the prey of humpback whales in Icy Strait. Herring schools were present at Point Adolphus throughout the summer, and humpback whales were consistently found feeding on them. In 1984, whales were also common 16 km west of Point Adolphus in South Passage, feeding on pollock. Feeding patterns of whales in Icy Strait were usually nonsynchronized dives by one to six whales.

Chatham Strait was surveyed only in 1984, and two different groups of whales were found. In northern Chatham Strait, a group, of whales was common in or near Tenakee Inlet. We encountered these whales feeding on fish on three occasions. Their feeding patterns consisted of synchronized cooperative feeding. Several whales would dive and emerge together, apparently forcing the fish to the surface where they would lunge through them.

Wore than 20 whales were subsurface feeding on a euphausiid layer extending from 140 to 180 m in southern Chatham Strait. Two or more whales would dive simultaneously, remain submerged about 10 minutes, then surface at approximately the same time near each other. Several vessels reported a group of whales in this area for at least 2 months.

Stephens Passage whales have been associated primarily with euphausiids. The main concentrations of euphausiids (and whales) have been found at Doty Cove, Point Glass, and Twin Point. The euphausiid layers were usually between 60 and 135 m and extended over several km^2. The main feeding patterns were similar to those in southern Chatham Strait; two or more whales would dive simultaneously, remain submerged approximately 10 minutes, then emerge at approximately the same time close together.

The majority of humpback whale feeding in Frederick Sound has been on euphausiids; only in one area were whales feeding on fish. The distribution of euphausiids changed often, and whales used multiple feeding strategies to capture them. We observed several changes in both the horizontal and vertical displacement of euphausiids; these changes were probably caused by a combination of tide and behavior. Whales used bubble netting and lunge feeding when euphausiid swarms were near the surface. When euphausiid layers were concentrated below 40 m, the whales used subsurface feeding strategies similar to those in Stephens Passage and Chatham Strait. Considerable vertical movement of the whales and euphausiids was common during the feeding periods. Whales feeding on fish were observed only near Five Finger Island, where groups of 5-1O whales would synchronize dives on schools of fish near the bottom.

Vessel-Whale Interactions

Our research has permitted us to approach numerous humpback whales with several different types and sizes of vessels. We found that feeding modes and possibly prey types and densities were important variables in humpback whale responses to vessels. Feeding whales usually did not respond to our presence, while nonfeeding whales usually moved away from the vessel or breached (Krieger and Wing 1984). Some reactions by feeding whales to vessels, however, were documented in 1984 by behaviorist C. Scott Baker who was contracted to census and identify whales as a supplement to the whale prey study.

The slow approach and maneuvering of the research vessels Acona or Searcher did not result in dramatic responses by whales. On four occasions in Glacier Bay, however, feeding whales appeared disturbed by our presence. Two whales were feeding on pollock near the southeast shore of Sturgess Island on 30 July. The Searcher entered the whale feeding area to sample the prey with a bottom trawl. As the vessel began its trawl, the whales moved around to the east side of the island. As the vessel ended its trawl, the whales moved away from the island and one of the individuals breached. On the morning of 4 August, two whales were feeding on a patch of euphausiids near the mouth of Muir Inlet. As the Acona moved into the area to assess the prey, the whales separated. A single whale was feeding on pollock near the south tip of Leland Island on 5 August. As the Searcher approached the area to trawl for prey, the whale left the area.

One incident of whales responding to our presence was' documented outside of Glacier Bay. The Searcher approached three whales feeding on a layer of euphausiids in southern Stephens Passage on 14 August. Their dive times were consistently 4 to 5 minutes followed by about 2 minutes on the surface. An approach to within 50 m of the surfacing whales resulted in a breakdown of the group's synchronized diving and a short "bout" of tail slapping. These whales moved away from the vessel and resumed feeding. Later the same day, a second pod of three whales in the same. area responded almost identically to our close approach. On 19 August, a pair of whales was feeding on capelin just north of Strawberry Island. The pair moved together when on the surface, usually within a small (50 m diameter) circle. The Searcher slowly approached the whales and was within 75 m when the engine was accidently engaged forward and accelerated. The whales vocalized in the air and appeared to be disoriented in their movement. One of the whales rolled on its side and slapped its fin on the water. The pair separated although both remained in the general vicinity and rejoined about 45 minutes later.

Oceanographic Conditions

Temperature and salinity gradients and high chlorophyll concentrations are often associated with areas rich in prey. Salinity temperature, and chlorophyll profiles were obtained during each survey period at several stations: Geikie Rock in central Glacier Bay, Bartlett Cove at the entrance to Glacier Bay, Point Adolphus in Icy Strait, and Doty Cove in Stephens Passage. The Geikie Rock area was characterized by a two-layered water column. The upper 30 m contained a surface pycnocline caused by a strong salinity gradient. Below 30 m, temperatures and salinities remained fairly constant with depth (Fig. 14). Subsurface temperatures and salinities remained almost constant between observations, whereas surface temperatures varied from 8.9" to 10.9" C and surface salinities varied from 18.3°/oo to 28.1°/oo (Table 5). Small increases in temperature and decreases in surface salinity at the Geikie Rock station may be associated with midsummer warming and increased freshwater runoff from glaciers in upper Glacier Bay, or an artifact of internal waves associated with tidal excursion. Comparisons of data from seven different years show considerable annual variation in both salinity and temperature in central Glacier Bay (Table 5). Chlorophyll-a levels did change considerably between

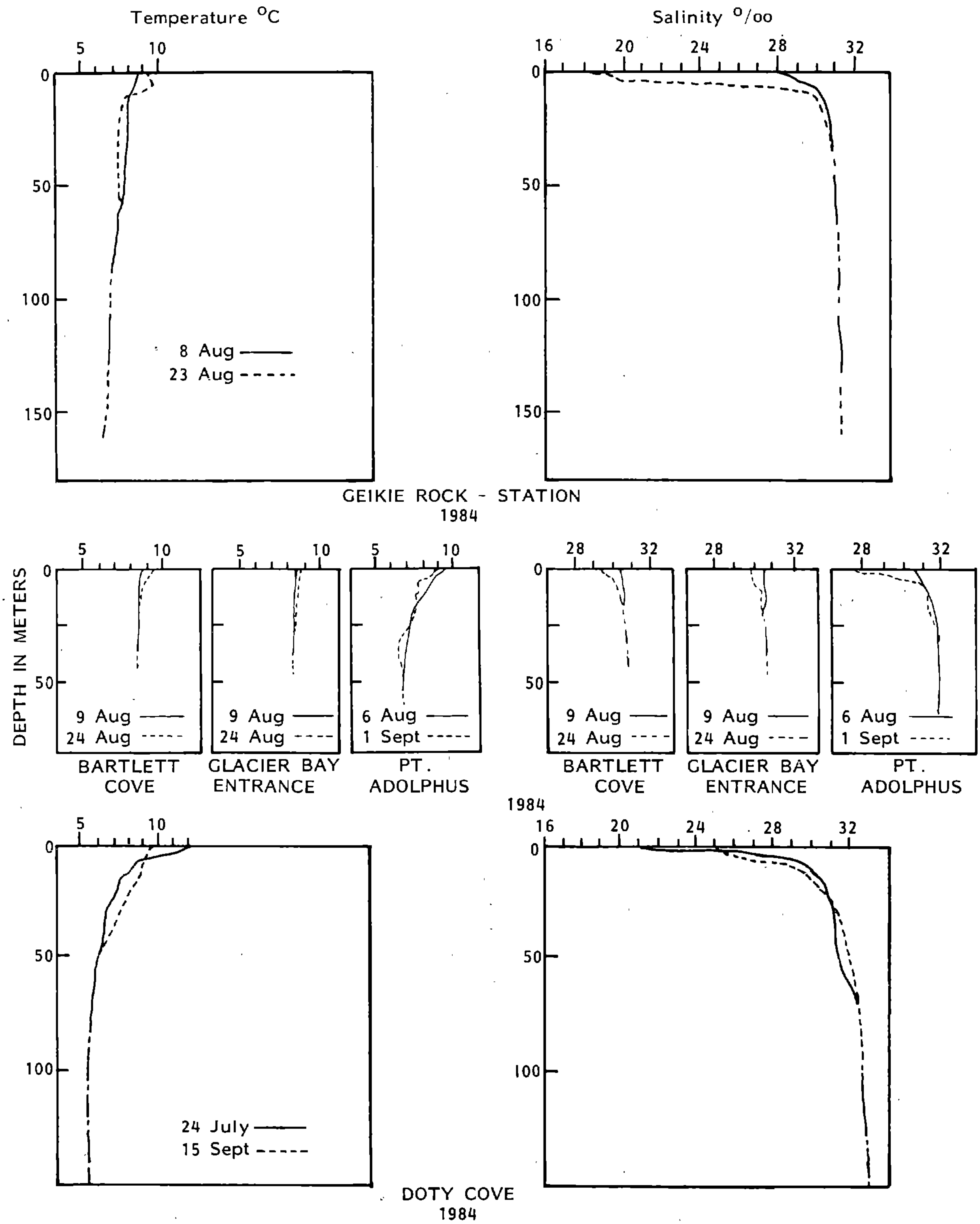

Figure 14. --Temperature and salinity profiles obtained in 1984 at humpback whale feeding sites.

Table 5.--Annual variations in temperature and salinity (July through September) in central Glacier Bay, southeastern Alaska.

Depth (m)	1965[a]	1966[b]	1967[b]	1981[c]	1982	1983	1984
0	∿8.0	-	-	6.9-8.6	8.6-9.9	8.6-9.6	8.9-10.9
50	5.8	>6.0	5.5	5.6-5.8	6.0-6.8	7.7-8.1	7.3- 7.8
100	5.5	6.0	4.0	-	5.0-5.9	6.8-7.3	6.8- 7.3
150	4.5	5.0	<4.0	-	4.8-5.4	6.2-6.9	6.5- 6.7
200	<4.0	4.4	<4.0		4.4-4.8	5.8-6.4	6.6
				Salinity (°/oo)			
0	∿30.0	-	-	20.5-25.4	20.4-23.1	23.8-26.7	18.3-28.1
50	30.8	30.2	31.0	31.6-32.0	30.9-31.3	30.1-30.7	30.6-31.8
100	31.1	31.0	31.2	-	31.1-31.4	30.3-30.7	31.1-31.4
150	31.2	31.1	31.4	-	31.2-31.4	30.7-31.0	31.2-31.3
200	31.3	31.1	31.5	-	31.2-31.4	30.8-31.0	31.2

[a] August data from Pickard 1967 and Matthews 1981.
[b] August data interpolated from Matthews 1981 Fig. 6.
[c] From Malme et al. 1982.

observations, with the highest concentration occurring on 11 September at Geikie Rock (Table 6).

Whale feeding was common in Sitakaday Narrows and along the southwest side of Young and Lester Islands. Oceanographic observations were obtained adjacent to these areas in Bartlett Cove and the Glacier Bay entrance. The observation sites were similar to the feeding areas since both were shallow (<65 m) with strong tidal mixing resulting in a nearly homogeneous water column (Fig. 14). The Bartlett Cove and Glacier Bay entrance profiles were similar with surface temperatures of 8.2° to 9.8° C and bottom temperatures of 7.9" to 8.3" C. Surface salinities varied from 29.7°/oo to 31.1°/oo, and bottom salinities varied from 30.9°/oo to 31.1°/oo. Bartlett Cove lacked a strong subsurface chlorophyll maximum because of strong vertical mixing (Table 6).

The water column at Point Adolphus was characterized by a series of weakly defined layers evident in both temperature and salinity profiles. Surface temperatures and salinities (9.3°-9.8° C, 28.0°/oo-29.8°/oo) and 50 m temperature and salinity (6.5° C, 32.0°/oo-32.2°/oo) changed little during the season, although the number of layers varied from three to five (Fig. 14). Point Adolphus also lacked a strong subsurface chlorophyll maximum because of strong vertical mixing (Table 6).

Oceanographic profiles of Doty Cove, showed increases in temperature and variations in salinity from 24 July to 15 September (Fig. 14). Surface temperatures varied from 9.2" to 11.9" C, and surface salinities varied from 14.4°/oo to- 25.0°/oo, possibly reflecting changes from the freshwater runoff of the nearby Taku drainage system. Variation at 50 m

Table 6.--Chlorophyll-a concentrations at four whale feeding sites in southeastern Alaska in 1984.

Locale	Date	Integrated concentration for surface 50 m mg Chl-a/m²	Maximum concentration Depth (m)	mg Chl-a/m³
Doty Cove	24 Jul 84	67.78	5	5.19
	6 Sep 84	68.16	5	8.18
	15 Sep 84	62.79	0	5.95
Geikie Rock	29 Jul 84	74.35	1	3.72
	8 Aug 84	104.27	5	5.15
	23 Aug 84	92.03	0	6.91
	31 Aug 84	57.64	5	3.64
	11 Sep 84	200.24	5	16.34
Bartlett Cove	31 Jul 84	65.40	5	2.11
	9 Aug 84	59.58	50	1.30
	24 Aug 84	70.00	5	1.92
	30 Aug 84	57.16	0	1.27
	12 Sep 84	46.02	5	1.04
Point Adolphus	6 Aug 84	55.43	0	1.72
	1 Sep 84	34.24	5	1.18

was 6.3° to 7.1" C and 31.3°/oo to 31.9°/oo. salinity. Below 75 m, temperature was a constant 6.3" C, whereas salinity increased from 31.5°/oo at 75 m to 33.0°/oo at 150 m. Thus, Doty Cove appeared to have a multiple-layer water column consisting of three layers: 1) a surface layer to 15 m with short-term temperature and salinity changes, 2) a layer between 15 and 75 m with a seasonal temperature increase of 1.5° C combined with small salinity changes, and 3) waters below 75 m with constant temperatures and slight salinity increases with depth. Integrated chlorophyll concentrations in Doty Cove were consistent (63 to 68 mg/m^2), but maximum chlorophyll-a/m^3 concentrations varied (Table 6).

Euphausiid Composition

Euphausiids dominated the deep scattering layers upon which humpback whales were feeding. Thysanoessa raschii was the dominant species in all catches sampled at whale feeding sites and monitoring stations during 1984 (Table 7). This species composed 70 to 100% of the catch in 56 of 63 Isaacs-Kidd midwater trawl samples in 1982, 1983, and 1984. Three other species, Euphausia pacifica, Thysanoessa longipes, and Thysanoessa, spinifera were also in the layers, but usually constituted less than 20% of the euphausiids caught. During 1984, the mean size of euphausiids in the scattering layer decreased as more juveniles joined the-aggregations.

DISCUSSION

We encountered humpback whale aggregates only in areas where concentrations of prey were extensive and dense. Most humpback whales observed in southeastern Alaska were feeding on euphausiids that were

Table 7.--Euphausiid species composition and mean sizes from Isaacs-Kidd midwater trawl catches in southeastern Alaska in 1984.

Area station	Date[a]	Species, % of population[b] *T. raschii*	*T. spinifera*	*T. longipes*	*E. pacifica*	Mean length (mm)	Mean weight[c] wet (mg)	drying (mg)
Glacier Bay								
Geikie Rk.	29 Jul (A)	86	-	14	-	5.28	0.2	0.1
Geikie Rk.	29 Jul	47	3	10	40	19.64	65.5	9.1
Geikie Rk.	29 Jul (B)	51	4	27	18	20.89	76.8	11.1
N. Marble Is.	8 Aug (A)	98	2	<1	<1	17.44	48.2	6.2
N. Marble Is.	8 Aug	96	2	<1	<1	19.44	63.8	8.8
Willoughby Is.	23 Aug	53	13	2	32	14.47	2.98	3.5
Geikie Rk.	23 Aug	88	5	<1	6	21.52	82.9	12.2
Tlingit Pt.	23 Aug	78	8	2	12	18.65	57.3	7.7
Geikie Rk.	31 Aug	91	4	<1	4	14.15	28.1	3.2
Geikie Rk.	11 Sep	88	6	<1	6	18.09	53.0	7.0
Frederick Sound								
Five Finger Is.	15 Aug	73	8	12	8	15.33	34.6	4.2
Five Finger Is.	14 Sep	99	<1	<1	<1	11.42	16.5	1.6
Stephens Passage								
Doty Cove	14 Aug	71	20	1	8	21.04	78.2	11.3
Doty Cove	5 Sep	93	4	<1	3	16.57	42.3	5.3
Twin Point	6 Sep	89	2	4	6	13.25	23.7	2.6
Doty Cove	15 Sep	90	4	<1	5	11.62	16.9	1.7
Doty Cove	15 Sep (N)	85	7	<1	8	12.74	21.1	2.3

[a] A = Net above scattering layer; B = Net below scattering layer; N = Night sample
[b] Populations of *Thysanoessa* spp. and *Euphausia* rounded to nearest point.
[c] Weights estimated from Mauchline 1980, ($\text{Log } W_w = -4.52 + 2.58 \text{ Log } L$.)
Samaoto 1976, ($\text{Log } W_d = -3.14 + 3.17 \text{ Log } L$.)

concentrated in deep scattering layers. The whales were usually in groups of three or more in specific localized areas in Stephens Passage, Frederick Sound, and southern Chatham Strait. Less than 25% of the whales were feeding on fish, and those feeding on fish were mainly in the Glacier Bay area and northern Chatham Strait. Except for the Point Adolphus area, fish concentrations showed considerable annual, seasonal, and spatial variations. The feeding patterns in Glacier Bay differed from other areas in that browsing on small fish schools was the most common feeding pattern. These feeding patterns apparently differed from those observed in the 1970's. The changes in feeding patterns indicate a change in prey which we believe accounts for most of the decrease in 'the usage of Glacier Bay by humpback whales.

Prey Changes

An important humpback whale prey in Glacier Bay during the 1970's was euphausiids. Large populations of euphausiids were regularly found at the surface in lower and mid-Glacier Bay from mid-July through August (Hale and Wright 1979). Jurasz and Palmer (1981) reported that 10 or more whales. were commonly seen feeding on euphausiids (determined visually and by plankton nets in the Marble Island area). A type of humpback whale feeding pertaining only to euphausiids (flick-feeding) had been observed only in Glacier Bay (Jurasz and Jurasz 1979). We rarely observed euphausiid feeding by whales in Glacier Bay, and we believe the levels of euphausiids have decreased in Glacier Bay since the active whale surface feeding observed in the 1970's. Bryant et al. (1981) sampled euphausiids in Glacier Bay and Frederick Sound in 1979 and found that the highest densities in Glacier Bay were lower than the lowest densities in Frederick Sound. During acoustic surveys from 1982 to 1984, the euphausiid densities in Glatier Bay were considerably less than those at whale feeding sites in Chatham Strait, Frederick Sound, and Stephens Passage. We documented only two cases of humpback whales feeding on euphausiids in Glacier Bay; these included two whales subsurface feeding in August 1984 and two whales surface feeding in August 1984. Point densities (g/m^3) of the Glacier Bay subsurface euphausiids approached the lower levels of euphausiid densities at other whale feeding sites, but the area densities (g/m^2) were considerably less than those of other whale feeding sites. We concluded that the levels of euphausiids in Glacier Bay in 1982, 1983, and 1984 were too low to instigate the type of feeding observed prior to 1978 in Glacier Bay.

Some of the changes in feeding behaviorof Glacier Bay whales can be associated with prey changes observed during standard hydroacoustic surveys. In 1982 and 1983, very few concentrations of fish or euphausiids were encountered during the standard transects. In 1984, concentrations of prey were encountered frequently during our standard transects, and area densities were consistently higher than those in 1982 and 1983 with highest densities occurring in late summer. This coincides with an increase in the number of' whales feeding in the transect areas, and with feeding occurring later in the year in 1984 compared to 1982 and 1983.

Spatial changes in Glacier Bay whale prey coincided with changes in the feeding locations of humpback whales. In 1982, the majority of humpback whales in Glacier Bay fed on capelin in Bartlett Cove. Hydroacoustic surveys were run in Bartlett Cove in 1983 and 1984 to monitor levels of capelin or other whale prey. No concentrations of whale prey were found in Bartlett Cove during 1983 and 1984, and no whales were known to use this area as a feeding area. In 1982 and 1983, the lower part of Glacier Bay was essentially void of'concentrated prey. In 1984, small schools of mixed baitfish were common in the lower bay, and humpback whales were frequently observed feeding on these schools. Small schools of walleye pollock were found only during the 1984 transects, and we documented whales feeding on these pollock in Glacier Bay and Icy Strait.

Oceanographic Conditions

A thorough study of the causes of changes in whale prey density and distribution was beyond our scope. Some of the physical oceanographic data collected, however, show seasonal changes occurring in Glacier Bay and partially describe the conditions that produce high densities of whale prey.

A low density euphausiid layer consisting mainly of *Thysanoessa raschii* was consistently found near Geikie Inlet in Glacier Bay. A possible reason for this layer was the distinct two-layered water column found there. High levels of chlorophyll-a concentrations also occurred in late summer, corresponding with the highest level of backscattering (euphausiids and fish) found in Glacier Bay during the 3-year study. Prior to our studies, *Euphausia pacifica* was 'reported as the abundant euphausiid in whale feeding areas of Glacier Bay (Earle 1979; Jurasz and Jurasz 1979; Bryant et al. 1981). The decrease in *Euphausia pacifica* may account for the overall decrease in Glacier Bay euphausiids.

Annual comparisons of the temperature and salinity data are difficult to interpret because oceanographic stations were not consistent from year to year. Some comparisons, however, are worth noting. Temperatures appear to have been higher in 1982, 1983, and 1984 than in the same general area during 1965, 1966, and 1967 (Table 6). Also, both higher temperatures and. prey densities were found in Glacier Bay in 1983 and 1984 than in 1982. These higher temperatures may be the result of the 1982-83 El Nino effect forcing warmer water into Glacier Bay. The changes in chlorophyll concentrations in two high-mixing areas in Glacier Bay (Bartlett Cove and Point Adolphus) did not appear related to changes in whale prey consisting of fish. In 1984, whales and herring were consistently present at Point Adolphus, whereas no significant quantities of baitfish or whales were found in Bartlett Cove.

The most concentrated whale feeding we observed in Stephens Passage was on euphausiids in Doty Cove. Doty Cove water temperatures were stable at approximately 75 m depth with only slight salinity increases with depth. This stabilization depth approximates the upper boundary of the daytime euphausiid layer. Maximum chlorophyll concentration (mg/m^3) also corresponded with the highest euphausiid densities and whale numbers in Doty Cove.

Whale Movements

Prior to 1980, Glacier Bay whales were considered a separate feeding group from those in Icy Strait. Darling and Jurasz (1979) reported that once the whales passed through the Sitakaday Narrows into Glacier Bay, they rarely returned to the lower bay until ready to migrate. We observed extensive whale movements between Glacier Bay and Icy Strait in 1984. During 19 days of observations in Glacier Bay and 8 days in Icy Strait, we recorded nine whales that moved from one area to the other; six of these whales moved between the areas more than once. The most extensive movement was by two of the historically best documented Glacier Bay whales. Several of the same whales were also seen at both Point Adolphus and Glacier Bay in 1982, and two of the whales were photographically documented to have moved from one area to the other and back (Baker et al. 1983). The changes in movement patterns are probably related to changes in prey types and location., Feeding prior to 1978 was reportedly on euphausiids in upper and mid-Glacier Bay. In recent years, feeding in Glacier Bay has been mainly on fish in the lower part of the bay adjacent to Icy Strait.' We do not believe that Glacier Bay whales and Icy Strait whales remain segregated when the prey conditions are like those observed in 1982-84.

Movement of Glacier Bay-Icy Strait whales to Frederick Sound and Stephens Passage occurs in late summer. In 1982, seven of the Glacier Bay-Icy Strait whales were later identified in Frederick Sound (Baker et, al. 1983). In 1983, two of the Glacier Bay-Icy Strait whales were identified in Stephens Passage (photo identifications were collected only once in Stephens Passage-Frederick Sound). In 1984, we identified 10 of the Glacier Bay-Icy Strait whales in Stephens Passage from mid-August to mid-September. The Glacier Bay-Icy Strait whales apparently moved to feed on the dense concentrations of euphausiids in the Stephens Passage-Frederick Sound area.

Whale Populations

Glacier Bay was thought to be a feeding ground for approximately one-third of the whales in southeastern Alaska (Hale and Wright 1979; Jurasz and Jurasz 1979). Whale censusing since 1979, however, shows that probably less than 10% of the total whales in southeastern Alaska feed in Glacier Bay. Baker et al. (1985) combined photographic identification of humpback whales in southeastern Alaska from 1979 through 1983. They identified a total of 326 whales and estimated an annual population of between 270 and 392 whales in southeastern Alaska.

In 1984 we identified 189 individual whales, 104 of which had not been identified from 1979 to 1983. This is the highest number of humpback whales recorded in southeastern Alaska in 1 year, probably because of an increase in effort to identify whales. The 189 whales do not include all of the whales in southeastern Alaska for several reasons: 1) whales in the southern part of southeastern Alaska were not photographed; 2) we did not cover all of the known areas of humpback whale concentrations in the northern part of southeastern Alaska; 3) not all whales were identified in areas we studied except possibly for Glacier Bay; and 4) whales arriving in the fall were not identified.

Whale-Vessel Interactions

Reactions of nonfeeding whales to our research vessels were usually more extreme than those of feeding whales. In most cases, nonfeeding whales would either breach or dive and move away from our approaching vessel. Feeding whales seldom reacted to our presence if we moved into an area at a slow, constant speed. Whales remained in the area to feed, often emerging and diving next to the vessel. Disruption of feeding whales by our research vessels, however, was noted on several occasions during 1984. In these observations, vessels were probably a factor contributing to the movement of whales away from prey. We believe the reaction of whales to vessel presence is dependent on several factors: 1) the speed, direction, and noise level of the vessel; 2) the type and density of prey; 3) the level of satiation and social interaction of the whales; and 4) the cumulative effect of more than one vessel.

SUMMARY

The main purpose of this research was to determine the relationship between prey levels and usage of Glacier Bay by humpback whales. Glacier Bay is one of many whale feeding areas in southeastern Alaska and appears to be a preferred range in early summer. In Glacier Bay, we found annual and seasonal variations in whale prey types, densities, and distributions. Euphausiids are documented as a main whale prey in Glacier Bay in the 197O's. However, from 1982 to 1984 in Glacier Bay, we found only low levels of euphausiids and most whales were feeding on fish. We believe that a decrease in euphausiid densities is the main reason for the change in the use of Glacier Bay by humpback whales. Annual and seasonal changes in whale prey do occur in Glacier Bay, and humpback whales adjust to these changes by varying their feeding patterns within the bay and across Sitakaday Narrows separating Glacier Bay from Icy Strait. We expect variations in Glacier Bay whale prey will continue and predict changes in humpback whale usage of Glacier Bay associated with the prey variations. The following is a summary of our major findings during our 3 years of whale prey research.

1. High concentrations of prey were always associated with humpback whale concentrations (three or more whales).
2. Glacier Bay was used mainly as an early summer feeding ground by approximately 10% of the whales that entered southeastern Alaska.
3. Fish were the main food of humpback whales in Glacier Bay and most of the feeding occurred in the lower part of the bay. In the early 1970's, euphausiids were reported as the main prey of Glacier Bay whales and most of the feeding occurred in the upper and midbay.

4. Whale feeding patterns in Glacier Bay consisted mainly of three or less whales browsing on schools of small fish. Whale feeding patterns in other areas of southeastern Alaska consisted mainly of three or more whales subsurface feeding on euphausiid layers.
5. The largest variations in species composition, seasonal abundance, and annual abundance were demonstrated in Glacier Eay.
6. Several changes in Glacier Bay whale movements were associated with prey variation:
   a. In 1982 humpback whales fed extensively on capelin in Bartlett Cove. Neither feeding whales or capelin schools could be found in Bartlett Cove in 1983 or 1984.
   b. In 1982 and 1983, very little prey or whale activity was observed in the Sitakaday Narrows. In 1984 fish schools and feeding whales were common in the Sitakaday Narrows,
   c. Young-of-the-year walleye pollock increased substantially in Glacier Bay in 1984 compared to 1982 and 1983, and became a main prey of the Glacier Bay whales.
   d. Transect prey levels and humpback whales increased in Glacier Bay in 1984 compared to 1982 and 1983.
   e. Transect prey levels were highest in Glacier Bay during late summer 1984, and whales remained in the area later than in 1982 and 1983.
7. Prior to 1978, whales were documented as entering Glacier Bay and remaining in the upper and midbay until they were ready to migrate. The majority of feeding we observed was in the lower bay, and movement between Glacier Bay and Icy Strait was common.

8. Regional movements of humpback whales were from Glacier Bay-Icy Strait into Stephens Passage or Frederick Sound.

9. The reaction of humpback whales to our research vessels depended on their feeding mode. Feeding whales did not commonly change their behavior when we approached 'them at a slow continuous speed. Nonfeeding whales would commonly move away from the vessel or breach.

ACKNOWLEDGMENTS

This work was funded, in part, by the National Park Service under Interagency Agreement No. IA 9700-3-8027. We thank M. Tolifson, Superintendent, and G. Vequist, resource specialist, for assistance and hospitality at the Glacier Bay National Park and Preserve during our field work. Whale behaviorist C. Scott Baker, Kewalo Basin Marine Mammal Laboratory, provided much insight on the identification, movements, and feeding behavior of humpback whales. Donald Patterson, Signy Patterson, and Larry Young, crew of the research vessel Acona, were always accommodating and cooperative in collecting whale prey data. Susan Swanner, University of Alaska, Juneau, provided species and size analyses of micronekton samples. Dr. Linda Jones and Mary Nerini of the National Marine 'Mammal Laboratory and Dr. Edmund Nunnallee of the Resource Assessment and Conservation Engineering Division, Northwest and Alaska Fisheries Center, assisted during part of the field work.

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