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Cetacean Habitats in the Alaskan Arctic

by

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ABSTRACT

Marine mammals can be used as indicators of environmental productivity because they must feed efficiently and therefore aggregate where prey is plentiful. Three species of cetaceans, bowhead whales (*Balaena mysticetus*), gray whales (*Eschrichtius robustus*) and white whales (*Delphinapterus leucas*) migrate to the Alaskan arctic each year to feed. These species have distinctly different feeding modes and forage at dissimilar trophic levels. Bowhead whales filter zooplankton from the water column, gray whales siphon infaunal crustaceans from the benthos and white whales catch a variety of nekton including crustaceans, cephalopods and fishes.

Line transect aerial surveys were conducted over the Alaskan Chukchi and Beaufort seas each late summer and autumn 1982-91. The resulting database, consisting of 633 flights, was post-stratified by survey type (transect legs only) and by sea state (Beaufort ≤ 04) to provide a database of random-transect cetacean sightings during good survey conditions. This necessarily meant disregarding sightings made during connect and search legs, which often included observations of feeding whales or cow-calf pairs, and of whales seen in rough seas. Post-stratification resulted in a cumulative (1982-91) database of 276,612 transect kilometers (t-km) of survey effort during which there were 556 bowhead, 608 gray and 835 white whale sightings.

Habitat partitioning and variability in habitat use among cetaceans offshore northern Alaska is poorly defined. Available data suggest that cetacean distribution and abundance patterns can be quantified on the basis of water depth and surface ice cover, and that these indices can be linked to large-scale oceanographic processes. In summer, mean depth and % surface ice cover were significantly different ($p<0.001$) among bowhead (900 m, 52%; $n=79$), gray (40 m, 1%; $n=497$) and white whales (1314 m, 60%; $n=143$). Similarly in autumn, mean depth and % ice cover were significantly different ($p<0.001$) among bowhead (109 m, 22%; $n=475$), gray (38 m, 7%; $n=111$) and white whales (652 m, 52%; $n=688$). In addition, mean depth and % ice cover were significantly different ($p< 0.001$) between summer and autumn for bowhead and white whale sightings. Currents are bathymetrically driven, and ice cover influenced by currents and wind, in the Chukchi and Beaufort Seas. Association of cetaceans with specific bathymetric and ice cover regimes provides a foundation for inference regarding inter-specific habitat selection, zones of productivity and insight to the role of cetaceans in Alaskan arctic ecology.

INTRODUCTION

Bowhead whales (*Balaena mysticetus*), gray whales (*Eschrichtius robustus*) and white whales (*Delphinapterus leucas*) migrate annually to arctic waters offshore of northern Alaska. All three species are apex consumers in the short food webs common to polar regions. Bowheads feed primarily on zooplankton, gray whales siphon epi- and infaunal crustaceans from the benthos and white whales prey on a variety of nekton including crustaceans, cephalopods and fishes. Patterns of apex-consumer abundance usually reflect areas of high productivity and prey abundance, which in turn are influenced by the physical environment (Ainley and DeMaster 1990). While this model has been verified for some mysticete whales in temperate waters (e.g. Kenney and Wishner 1995), the association of cetaceans with oceanographic features in the arctic has not been examined rigorously.

Extensive observational data on bowhead, gray and white whales were collected offshore of northern Alaska during aerial surveys each late summer and autumn 1982-91. Although various descriptive accounts of cetacean distribution and relative abundance have been drawn from these data (e.g. Moore 1992; Moore and Reeves 1993; Moore and Clarke 1992, 1993; Moore and Ljungblad 1984; Moore et al. 1993, 1989, 1986; Clarke et al. 1989, 1993), temporal and spatial scales of analyses varied, impeding comparisons among species. This paper provides an integrated descriptive comparison of cetacean habitats in the Alaskan arctic for three species that: (1) migrate to and feed predominantly in arctic waters; and (2) forage at dissimilar trophic levels. Inter-specific comparisons of habitat partitioning among these whales will provide new insight to zones of productivity and the role of cetaceans in Alaskan arctic ecology.

Background

Physical Oceanography Offshore Northern Alaska

Northern Alaska is bounded by the Beaufort and Chukchi seas, which represent distinctly different bathymetric habitats (Figure 1A). The Chukchi is a broad shallow (*ca.* 50 m) sea, with topographic features comprised of Herald and Hanna shoals, and Barrow, Herald and Hanna submarine canyons. Conversely, the Beaufort Sea's narrow continental shelf is demarcated by a steep slope that drops to abyssal depths within 70-150 km of shore. Current flow is bathymetrically driven in both seas (Figure 1B). Inflow through Bering Strait bifurcates near 70°N latitude; saline Bering Sea Water (BSW: 32.2-33 psu) flows northwest and enters the Arctic basin through Herald Canyon, while the comparatively fresh Alaskan Coastal Water (ACW: 32.1-32.5 psu) flows northeastward along the coast and enters the Arctic basin through Barrow Canyon (Aagaard 1987). At Barrow Canyon, the ACW encounters a third major water mass, the resident Chukchi water (RCW), which is comprised of water that has remained on the shelf from the previous winter. Both BSW and ACW are identifiable on the Beaufort

Sea outer shelf (seaward of 50 m) as the eastward flowing Beaufort Undercurrent (BU) (Aagaard 1984). The warm relatively fresh ACW mixes with ambient surface waters as it moves eastward and is not clearly identifiable east of about 147°W, while the BSW can be traced to at least 143°W. Although the northern boundary of the BU is poorly defined, it is thought to extend from 50-2500 m isobaths, a horizontal distance of 60-70 km. Seaward of the BU the Beaufort Gyre flows westward, while current flow along the inner shelf (<50 m) shifts from eastward to westward with wind forcing (Fissel et al. 1987).

Ice covers the Beaufort and Chukchi seas from December to July. Maximum ice cover extends south to about 57-60°N in March; minimum ice cover occurs between 72-75°N in September (Niebauer and Schell 1993). Inter-annual variation in the position of the ice edge can be as great as 400 km, while daily ice drift rates range from about 2 to 9 km/d. Sharp temperature and salinity fronts are associated with the marginal ice zone (MIZ), a 10-100 km wide dynamic boundary between ice-covered and open ocean (Paquette and Bourke 1981). MIZ deformation in the Chukchi Sea is directly influenced by current flow (Bourke 1983), while wind stress plays a greater role in ice-edge location in the Beaufort Sea.

Cetacean Migration and Feeding Patterns in the Alaskan Arctic

Bowhead, gray and white whales are the only cetacean species that routinely migrate to and feed in the Alaskan arctic. Bowheads, the only mysticete endemic to arctic and sub-arctic waters, migrate north each spring from wintering areas along the ice edge in the Bering Sea to summer feeding areas in the Canadian Beaufort Sea (Moore and Reeves 1993). Bowheads continue to feed during the autumn migration across the Beaufort and Chukchi seas (Ljungblad et al. 1986; Moore and Clarke 1992). Stomachs of whales killed by subsistence hunters in the eastern Alaskan Beaufort Sea usually contain copepods, while those from whales taken in the western Alaskan Beaufort Sea usually contain euphausiids (Lowry 1993). Gray whales migrate to the northern Bering and Chukchi seas to feed, primarily on benthic amphipods, from late April through November (Moore et al. 1986; Clarke et al. 1989; Nerini 1984). Gray whales are unique among mysticetes in that they suction benthic prey from the sediment (Nerini and Oliver 1983). Suction feeding creates large excavations (2-20 m^2) that significantly alter benthic community structure (Oliver and Slattery 1985) and create a prey source for seabirds, as plumes of mud are brought to the surface (Obst and Hunt 1990). White whales (also belukha or beluga) follow a migration cycle similar to bowheads. They prey on a variety of benthic and pelagic prey although diet varies with season, location, age and body size (Stewart and Stewart 1989). Stomach content data are unavailable for white whales in the Alaskan Beaufort and Chukchi seas (Frost and Lowry 1984).

METHODS

The study area extended north from Bering Strait (65°N) to 72°N, between the International Date Line (IDL: ca. 169°W) and 140°W, near the U.S.-Canadian border. This area was divided into blocks suitable for line transect surveys, with blocks 1-12 comprising the Alaskan Beaufort Sea and blocks 13-25 the Alaskan Chukchi Sea (Figure 2A). In 1987, surveys to 73°N were initiated west of 154°W longitude, adding blocks 12N-16N to the survey schedule.

Line transect aerial surveys were the sampling method for all years 1982-91. Each survey consisted of transect, connect and search legs flown in survey blocks (Figure 2B). The start, end and turning points of each transect leg were determined randomly, so sightings made during the survey of transect legs are considered a random sample (Buckland et al. 1993). Survey data were recorded on a portable computer aboard the aircraft. The data entry format consisted of 23 variables presented to the data recorder in menu format (Table 1: A-W). The first four variables (Table 1: A-D) were recorded automatically at each entry via an interface that connected the computer to the aircraft's global navigation system and radar altimeter. Responses to the remaining variables were selected by the data recorder. All entries were coded by survey type (Table 1:E).

Surveys were flown at 152 to 458 m altitude at 222 to 296 km/h in two types of high-wing aircraft. Higher altitudes were maintained when weather permitted to increase visual range and reduce the possibility that whales might be disturbed by the aircraft. Each aircraft was equipped with a Global Navigation System 500 that provided a continuous display of position (0.6 km/survey hour precision, ideally) and was programmable for transect turning points. Surveys were usually curtailed when visibility was <1km or sea state exceeded Beaufort 05 for >0.5h.

RESULTS

Survey Effort and Database

Cumulative survey effort consisted of 633 flights between 10 July 1982 and 31 October 1991. Summer surveys were flown in July through 1985, and in August through 1986. Surveys in September and October continued through 1991. The cumulative database was post-stratified by survey type (transect-legs only) and by sea state (Beaufort≤04) to provide a baseline of random sampling and cetacean sightings during good survey conditions (Table 2; Figure 3). This necessarily meant disregarding sightings made during connect and search legs, which often included observations of feeding whales or cow-calf pairs, and of whales seen in rough seas. Post-stratification resulted in a cumulative (1982-91) database consisting of 276,612 transect kilometers (t-km) of survey effort during which there were 556 bowhead, 608 gray and 835 white whale sightings.

Cetacean Distribution and Habitat Associations

Bowhead, gray and white whale distribution was separable on the basis of bathymetry and surface ice cover in both seasons (Table 3). In summer, bowheads were seen east of 148°W in the Alaskan Beaufort Sea, generally seaward of the continental shelf in waters averaging 900 m deep (Figure 4). Gray whales were concentrated south of Bering Strait (Chirikov Basin), and along the northeastern Alaskan coast in water averaging 40 m deep (Figure 5). White whales were distributed across the Alaskan Beaufort Sea, generally seaward of the continental slope in water averaging 1314 m deep (Figure 6). Depth at sightings was significantly different among the three species (ANOVA $F=290$, $p<0.001$), with all pairs significantly different at $p = 0.05$.

In autumn, bowhead and white whales were distributed across the Alaskan Beaufort Sea and into the northeastern Chukchi Sea (Figures 4 and 6). Bowheads were shoreward and white whales seaward of the continental shelf break in water averaging 109 m and 652 m deep, respectively. Gray whales were distributed southwest of Pt. Hope, along the northeastern Alaskan coast and in shoal waters west of Pt. Barrow (Figure 5); average water depth was 38 m at gray whale sightings. As in summer, depth at sightings was significantly different among the three species (ANOVA $F=107$, $p<0.001$), with all pairs significantly different at $p = 0.05$.

The three species were also associated with distinctly different surface ice cover habitat. In summer, ice cover averaged 52% at bowhead sightings, 1% at gray whale sightings and 60% at white whale sightings (Table 3). Ice cover was significantly different among the three species (ANOVA $F=558$, $p<0.001$), with all pairs significantly different at $p = 0.05$. In autumn, ice cover averaged 22% at bowhead sightings, 7% at gray whale sightings and 52% at white whale sightings. Again, ice cover was significantly different among species (ANOVA $F=146$, $p<0.001$), with all pairs significantly different at $p = 0.05$.

Bowhead and white whales exhibited a seasonal shift in habitat association, but gray whales did not. Depth at sightings was significantly different between summer and autumn for bowhead ($t=439$, $p<0.001$) and white whales ($t=262$, $p<0.001$). In both cases, the shift was from deeper water during summer to shallower water during autumn (Table 3). Seasonal ice cover associations were also significantly different for bowhead ($t=52$, $p<0.001$) and white whales ($t=12$, $p<0.001$). In both cases, the shift was from heavier ice cover in summer to lighter ice cover in autumn. This may be a reflection of the shift inshore to shallower water, as ice conditions are generally lighter near shore compared to offshore in the Beaufort Sea during autumn.

DISCUSSION

Bowhead, gray and white whales were associated with distinctly different bathymetric and ice cover habitats in summer and autumn (Table 4). White whales were consistently associated with the deepest water and heaviest ice cover, gray whales with the shallowest water and lightest ice cover, with bowhead habitat intermediate to the two. Further, the association of each species with specific bathymetric habitats allows inference to the current regime occupied (see Figure 1B). Bowheads and white whales were associated with the Beaufort Undercurrent (BU) in summer. In autumn, bowheads moved into shallow shelf waters shoreward of the BU, while white whales remained in habitat associated with the BU. In the Chukchi Sea, bowhead and white whales were associated with Alaskan Coastal Water (ACW) and Beaufort Sea Water (BSW) channeled by Barrow and Herald Canyons. Gray whales were found in shoal areas influenced by ACW and BSW in both seasons.

The association of bowhead, gray and white whales with distinctly different bathymetric and ice cover habitats in summer and autumn likely reflects differences in feeding modes and preferred prey among the three species. Bowheads feed by straining relatively large zooplankton from sea water on long (to 4.6 m) very fine-bristled baleen (Lowry 1993). Copepods (principally *Calanus glacialis* and *C. hyperboreous*) were the dominant prey in 14, and euphausiids (*Thysanoessa raschii*) the dominant prey in 13, of 35 stomachs analyzed from whales taken by Alaskan whalers. Gray whales suction prey from sediment, then strain prey and sediment on short (to 25 cm) coarse-bristled baleen (Nerini 1984). On the northern feeding ground, benthic amphipods are the dominant prey, with one or two species often comprising 90% of a whale's stomach contents. Species from six amphipod genera (*Ampelisca, Byblis, Haploops, Atylus, Anonyx* and

Pontoporeia) were dominant in stomachs from 324 whales taken by Russian whalers offshore Chukotka. White whales use teeth to feed on a variety of fish, crustaceans and mollusks (Stewart and Stewart 1989). Although there are no direct observations of stomach contents for the Beaufort Sea white whale population, Frost and Lowry (1984) speculate that Arctic cod (*Boreogadus saida*) comprised 80% of the diet, with the other 20% made up of shrimps, cephalopods and other fishes.

It appears that bowhead and gray whales rely on finding relatively dense prey concentrations. In the Canadian Beaufort Sea, bowheads were often associated with frontal features thought to concentrate prey at the convergence of the MacKenzie River plume and the Beaufort Sea (Bradstreet et al. 1987). In the western Chukchi Sea, feeding bowheads were associated with a 5m x 8km patch of zooplankton that contained the euphausiid *T. raschii*, which occurred at a sharp salinity (proxy density) gradient at about 30 m depth offshore the Chukotka peninsula (Moore et al. 1995). Gray whales exploit tube-building amphipod communities in the Chirikov Basin, just south of Bering Strait, characterized by low species diversity, high biomass and the highest secondary production rates reported for any extensive benthic community (Highsmith and Coyle 1990, 1992). The association of bowheads and gray whales with distinct benthic habitats suggests specific zones of productivity for their preferred prey.

Although little is known about white whale foraging in the Alaskan Beaufort and Chukchi seas, dense concentrations of prey appear important in other areas where feeding has been studied (Hazard 1988). In the Canadian High Arctic, large schools of Arctic cod were preyed upon by hundreds of white whales, to the point of being driven ashore (Welch et al. 1993). The distribution of Arctic cod offshore Alaska is unknown. In the Canadian High Arctic fish, presumably Arctic cod, were found in four zones (near the ice undersurface, ~40m, 80-100m, 150-200m) that corresponded roughly with the distribution of large zooplankters (Crawford and Jorgenson 1990). The ice edge is postulated as a site of high fish production due to local oceanic upwelling (Dunbar 1981), and birds and marine mammals presumably aggregate there due to enhanced feeding opportunities (Bradstreet and Cross 1982). The association of white whales with basin and continental slope bathymetric habitat and relatively heavy surface ice cover in the Alaskan Beaufort and Chukchi seas may suggest zones of zooplankton-fish productivity that whales can exploit.

The Alaskan Arctic is a dynamic ecosystem. The influx of North Pacific water

(ACW + BSW) through Bering Strait defines the character of the Chukchi Sea and strongly influences the hydrography of the Beaufort Sea. The eastward-flowing BU provides an important dispersal and transport mechanism from the northern Bering Sea. The seasonal inflow cycle peaks in June and January, and displays strong wind-dependent inter-annual variation (Coachman and Aagaard 1988; Aagaard et al. 1985). Cetaceans in the arctic rely on finding dense prey aggregations that appear related to these current regimes and patterns of ice cover. Further investigation of habitat partitioning among these whales will provide new insight to the role of cetaceans in arctic ecology.

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Table 1. Data entry format on the portable computer onboard the survey aircraft.

A. GMT

B. Latitude

C. Longitude

D. Altitude

E. Reason for Entry
- 0. flight aborted
- 1. sight on transect
- 2. sight off transect
- 3. sight search survey
- 4. position-on transect
- 5. position-on connect
- 6. position-on search
- 7. start transect
- 8. end transect
- 9. divert transect
- 10. resume transect
- 11. deadhead

F. Species
- 0. no sighting
- 1. bowhead whale
- 2. gray whale
- 3. belukha
- 4. walrus
- 5. bearded seal
- 6. ringed seal
- 7. polar bear
- 8. ukn cetacean
- 9. ukn pinniped
- 10. orca
- 11. minke
- 12. fin
- 13. vessel

G. Sighting Cue
- 0. no cue
- 1. splash
- 2. blow
- 3. body
- 4. ice tracks
- 5. mud plumes
- 6. birds or fish
- 7. kill sight
- 8. oil sight

H. Habitat
- 0. open water
- 1. tide rip
- 2. on ice
- 3. on land

I. Behavior
- 0. unknown
- 1. dive
- 2. rest
- 3. swim
- 4. mate
- 5. feed
- 6. mill
- 7. spy hop
- 8. breach
- 9. roll
- 10. slap
- 11. u/w blow
- 12. cow/calf
- 13. dead
- 14. run
- 15. thrash

J. Size
- 0. unknown
- 1. calf of year
- 2. immature
- 3. adult
- 4. large adult
- 5. cow/calf pair

K. Total Number

L. Calf Number

M. Clinomter Angle

N. Swim Direction (°mag)

O. Swim Speed (kts)
- 0. unknown
- 1. still (0 kt)
- 2. slow (<1 kt)
- 3. medium (1-3 kts)
- 4. fast (>3 kts)

P. Aircraft Response
- 1. yes
- 2. no
- 3. unknown

Q. Repeat Sighting
- 1. yes
- 2. no
- 3. unknown

R. Observer

S. Weather
- 1. clear
- 2. partly cloudy
- 3. fog
- 4. overcast
- 5. precipitation
- 6. low ceiling
- 7. haze
- 8. glare

T. Visibility (left/right)
- 0. 0 km
- 1. <1 km
- 2. 1-2 km
- 3. 2-3 km
- 4. 3-5 km
- 5. 5-10 km
- 6. unlimited

U. Ice Coverage (%) and Type
- 0. no ice
- 1. floe
- 2. broken floe
- 3. pack
- 4. pack/floe
- 5. grease/new
- 6. shorefast
- 7. lead
- 8. bkn floe and new
- 9. new and bkn floe

V. Beaufort Sea State
- 0. B0 glassy <1 kt
- 1. B1 lt ripple 1-3 kts
- 2. B2 sml waves 4-6 kts
- 3. B3 sctrd caps 7-10 kts
- 4. B4 num caps 11-16 kts
- 5. B5 many caps 17-21 kts
- 6. B6 all caps 22-27 kts
- 7. B7 brkng waves 28-33 kts
- 8. B8 foam 34-40 kts
- 9. N/A not applicable

W. Water Color
- 0. N/A
- 1. light blue
- 2. dark blue
- 3. light green
- 4. dark green
- 5. black
- 6. muddy
- 7. tideline

Table 2. Cumulative (1982-91) semi-monthly transect survey effort (t-km), number of cetacean sightings (No. SI) and sighting rate (SI/100 t-km).

DATE	EFFORT (t-km)	No. SI (SI/100 t-km) Bowhead Whale	Gray Whale	White Whale
10-31 July	16,634	0 (-)	489 (2.94)	10 (0.06)
1-15 August	15,773	44 (0.28)	3 (0.02)	39 (0.25)
16-31 August	28,321	35 (0.12)	5 (0.02)	97 (0.34)
Subtotal$_{summer}$	60,728	79 (0.13)	497 (0.82)	146 (0.24)
1-15 September	44,619	61 (0.14)	22 (0.05)	115 (0.26)
16-30 September	61,983	220 (0.35)	29 (0.05)	238 (0.38)
1-15 October	70,646	158 (0.22)	24 (0.03)	252 (0.36)
16-31 October	38,636	38 (0.10)	36 (0.09)	84 (0.22)
Subtotal$_{autumn}$	215,884	477 (0.22)	111 (0.05)	689 (0.32)
Grand Total	**276,612**	**556 (0.20)**	**608 (0.22)**	**835 (0.30)**

Table 3. Mean depth and ice cover at bowhead, gray and white whale sightings offshore northern Alaska in summer (July-August) and autumn (September-October).

SUMMER

	Depth (m) X	sd	SE	Ice (%) X	sd	SE
Bowhead Whale (n = 79)	900	861	96.87	52	36	4.09
Gray Whale (n = 497)	40	7	0.32	1	5	0.23
White Whale (n = 146)	1314	1166	96.51	60	38	3.15

AUTUMN

	Depth (m) X	sd	SE	Ice (%) X	sd	SE
Bowhead Whale (n = 477)	109	332	15.20	22	35	1.61
Gray Whale (n = 111)	38	15	1.40	7	21	1.95
White Whale (n = 689)	652	881	33.58	52	37	1.41

Table 4. Average bathymetry, ice cover and associated current regime for cetaceans in the Alaskan Arctic in summer and autumn.

SPECIES	BATHYMETRY (m) Summer	Autumn	ICE COVER (%) Summer	Autumn	CURRENT REGIME Summer	Autumn
Bowhead Whale	900	109	52	22	BU	shelf/ACW
Gray Whale	40	38	1	7	shoal	shoal
White Whale	1314	652	60	52	BU	BU/ACW

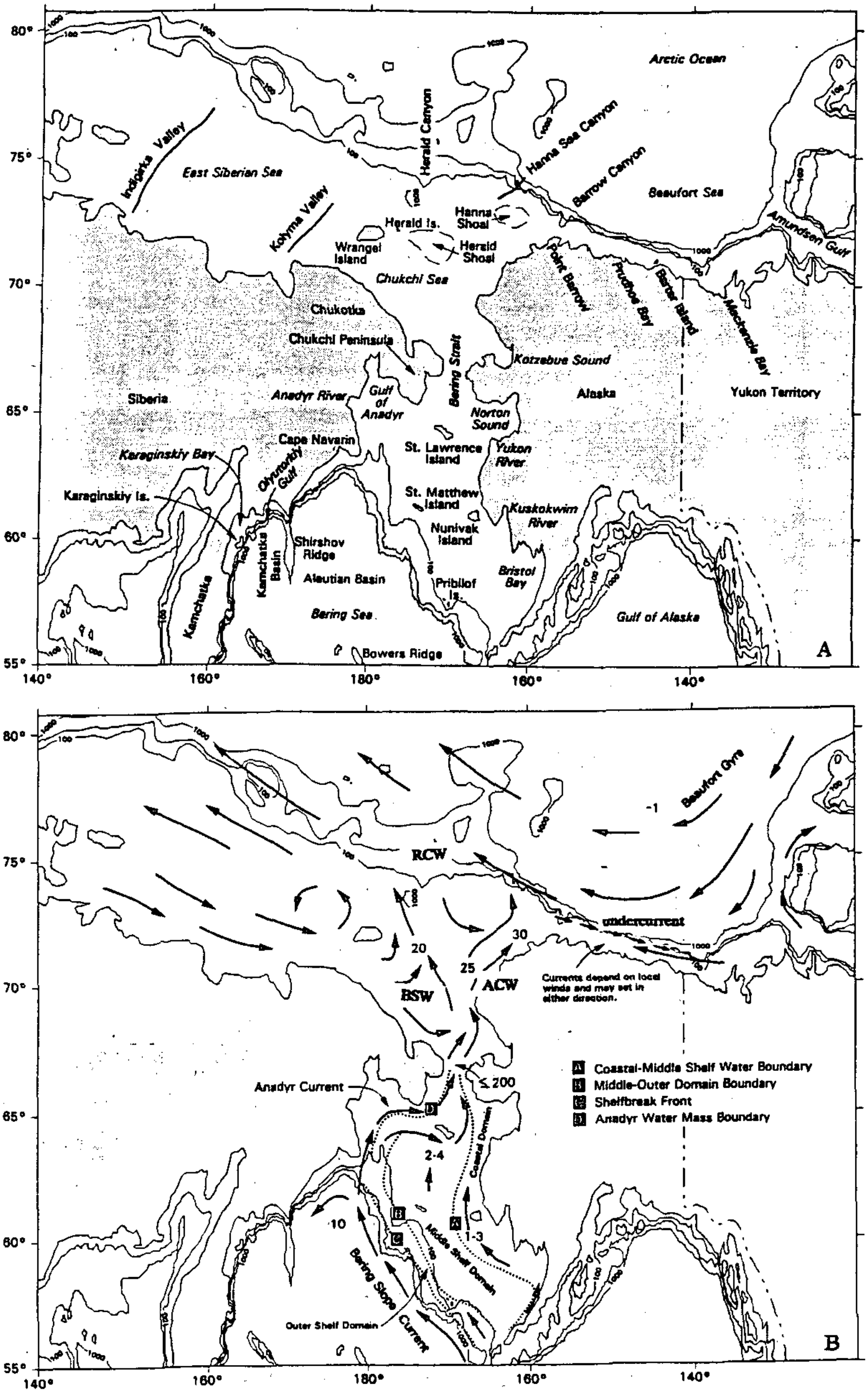


Figure 1. Bathymetry (A) and surface currents (B) in the Chukchi and Beaufort Seas. Modified from Niebauer and Schell (1993).

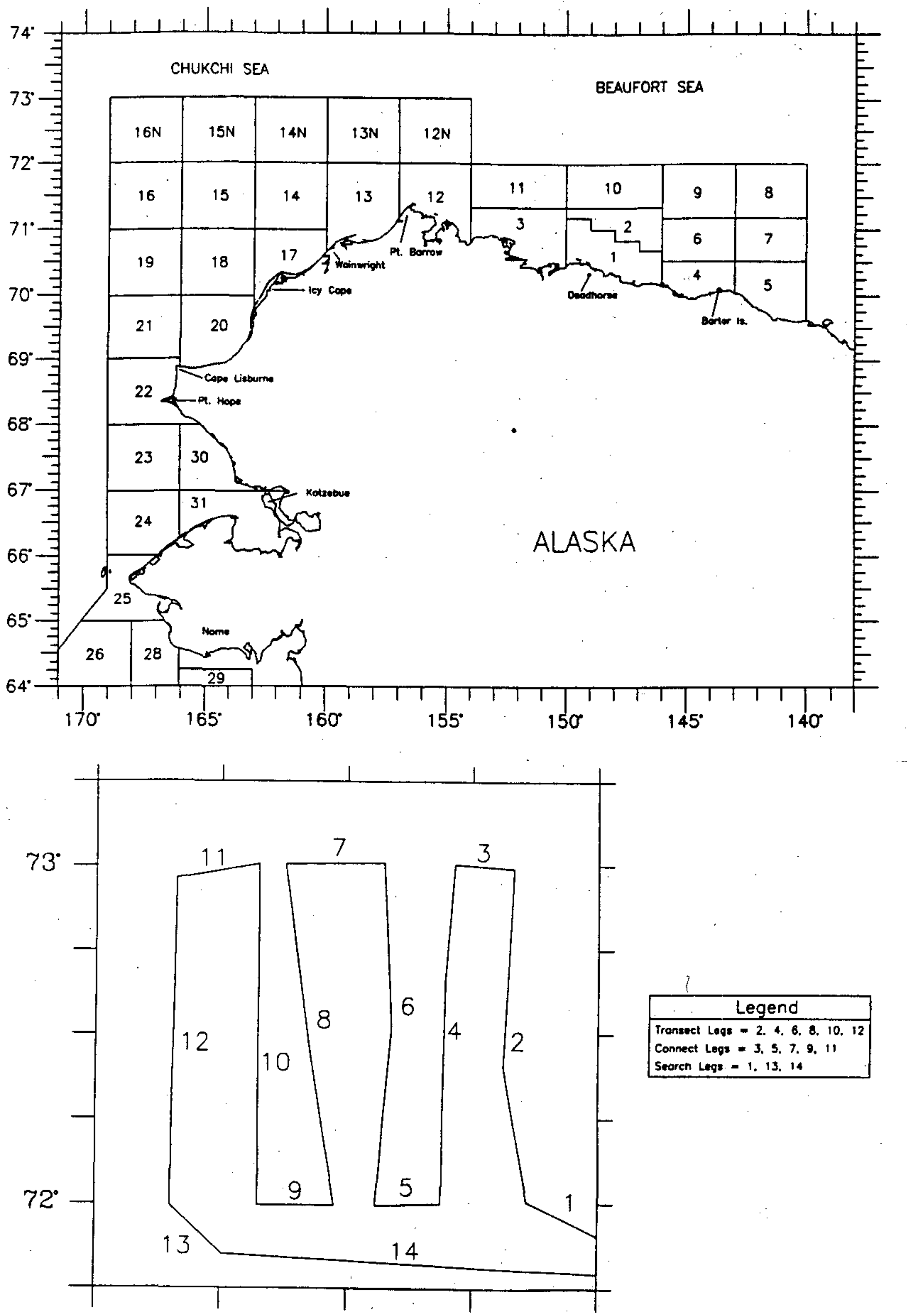
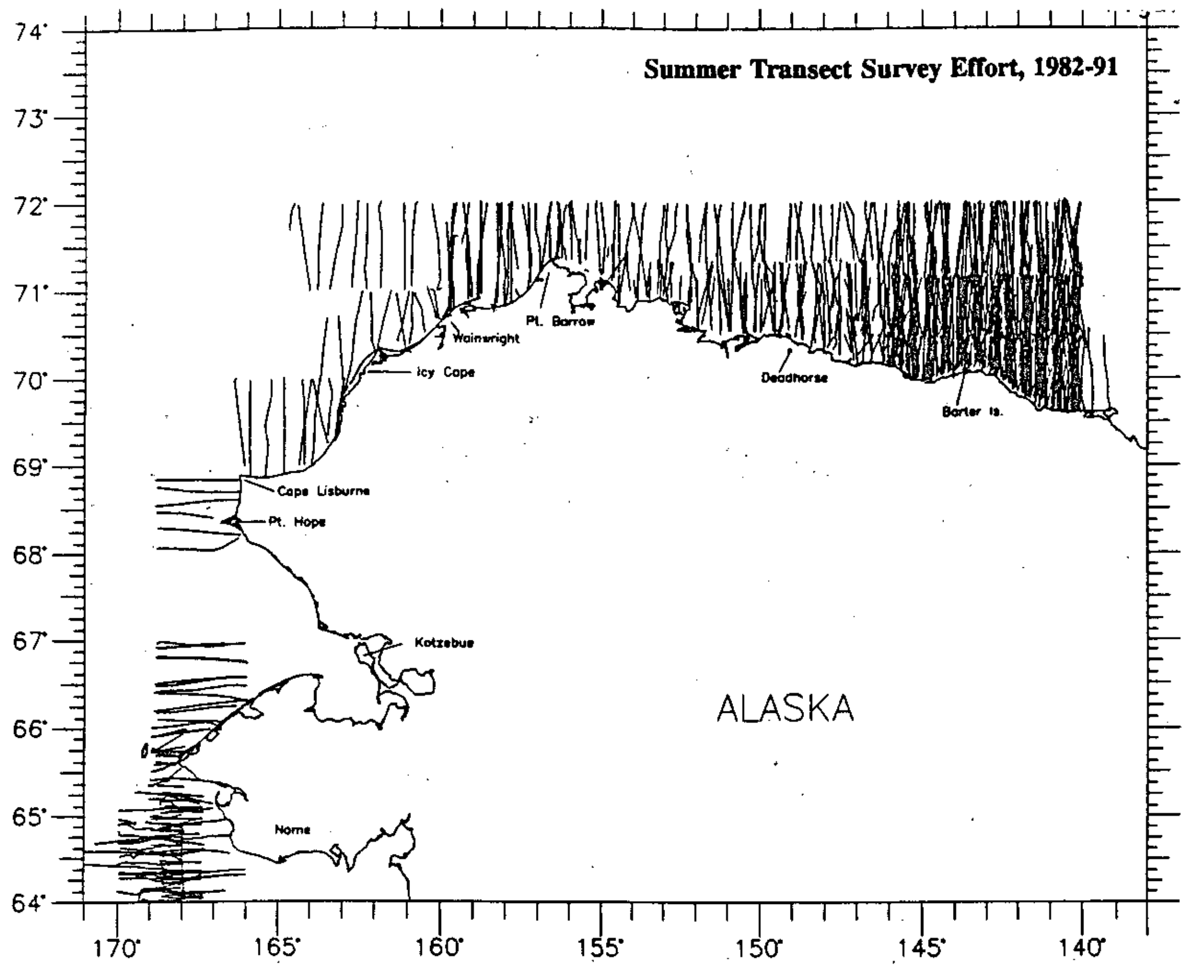


Figure 2. Aerial survey study area and survey blocks (A) and typical survey flight track (B) depicting transect, connect and search legs.



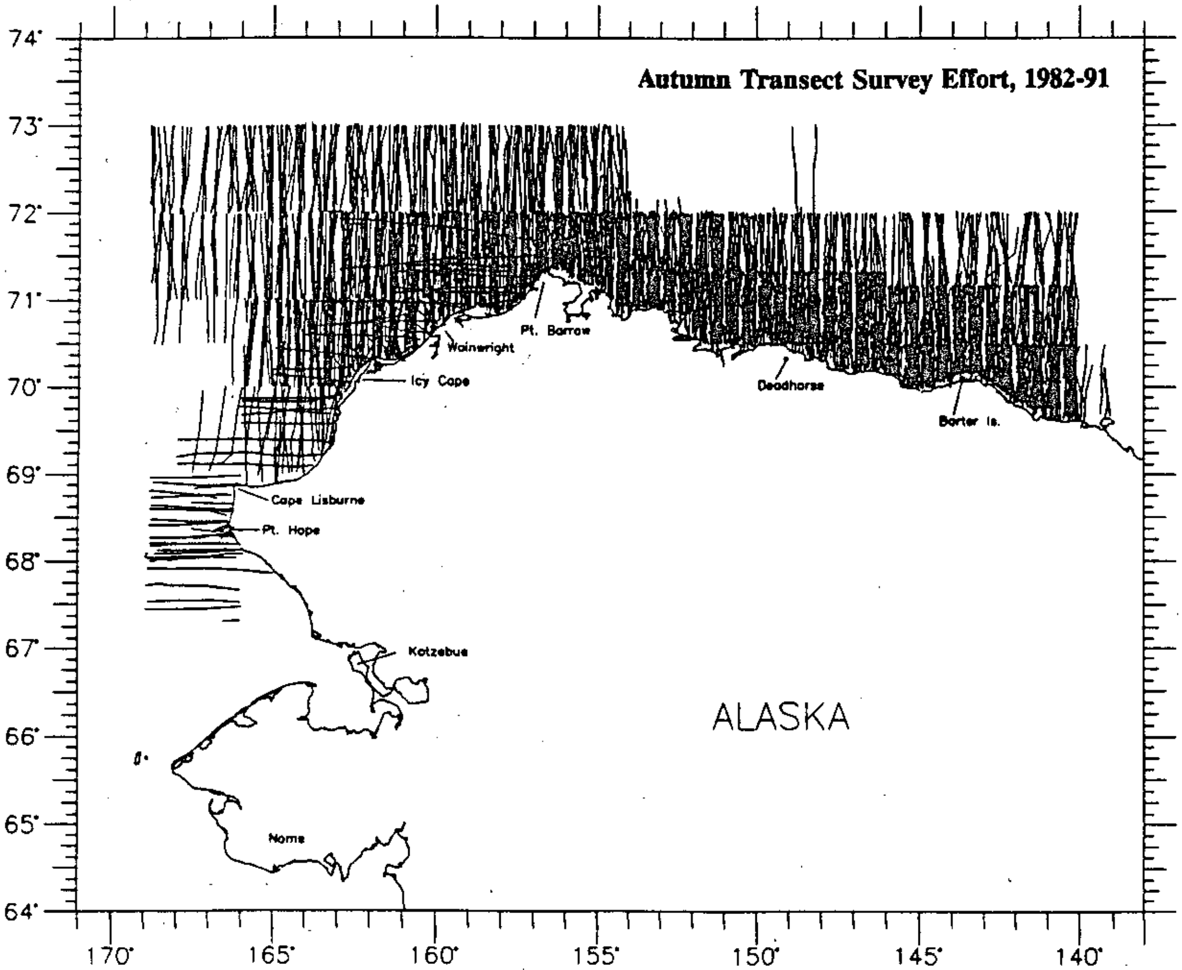


Figure 3. Summer (July-August) and autumn (September-October) survey effort offshore northern Alaska, 1982-91. Only random-transect survey legs are plotted.

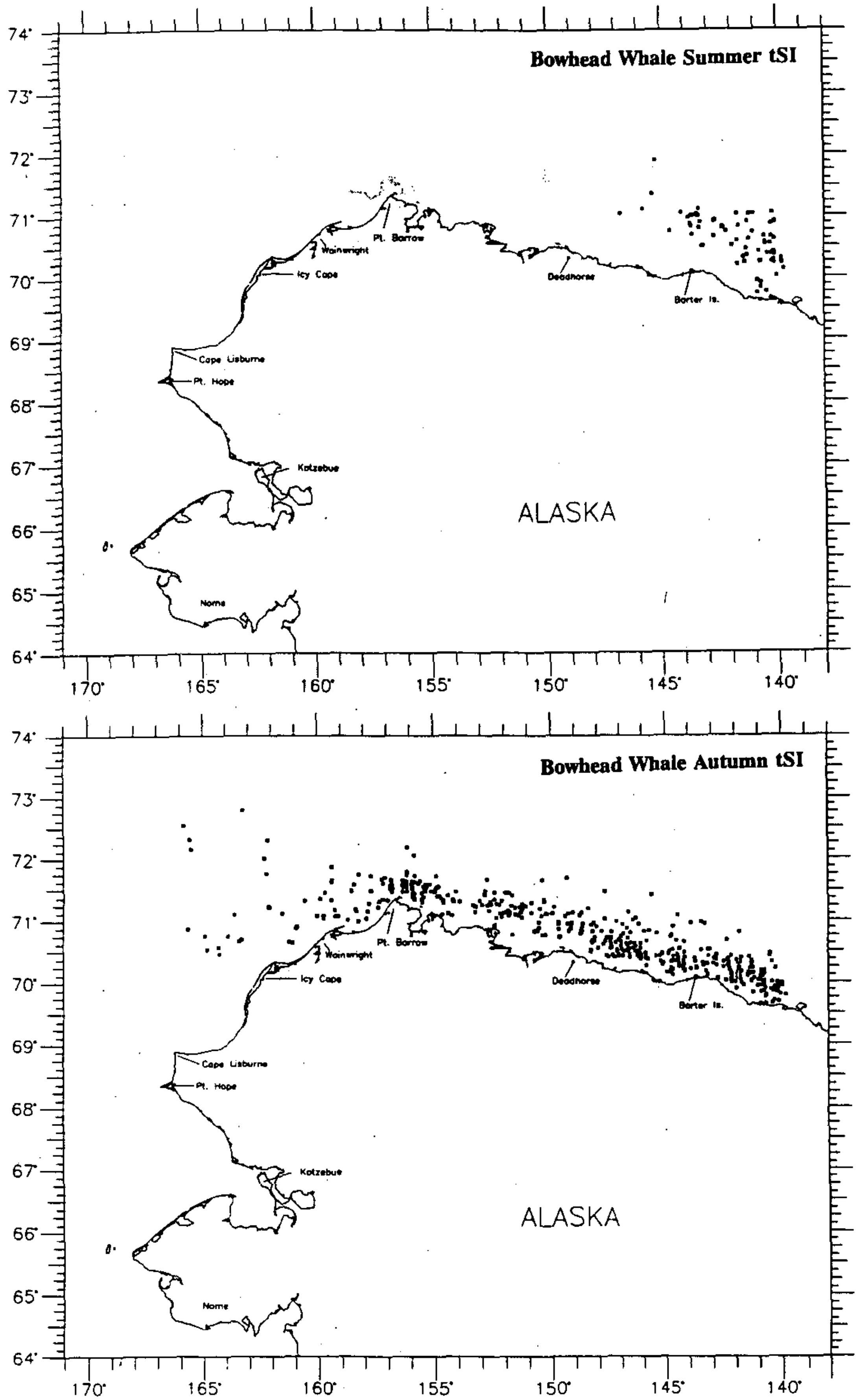


Figure 4. Bowhead whale distribution in summer (July-August) and autumn (September-October). Transect sightings (tSI) only; sample sizes listed in Table 2.

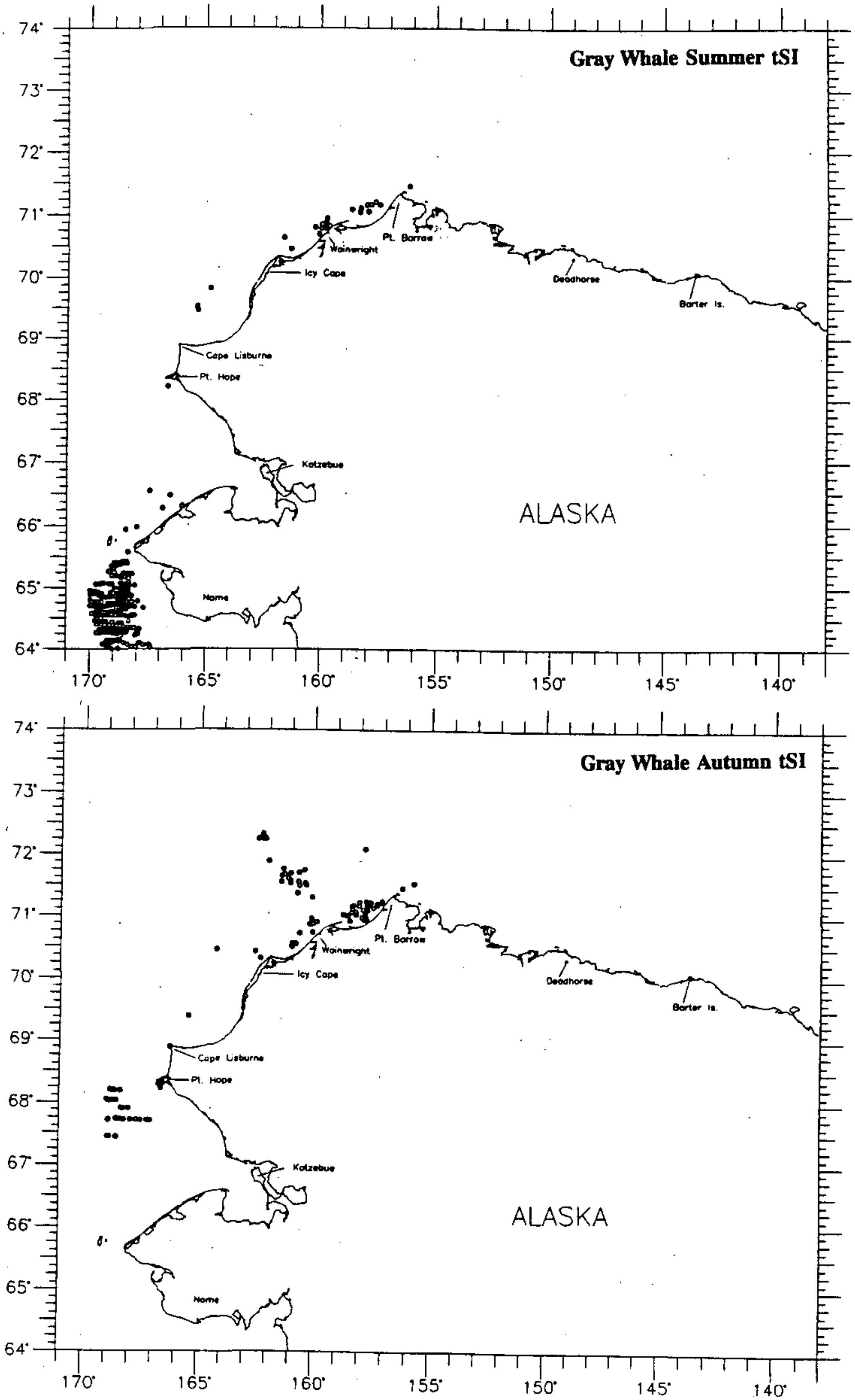


Figure 5. Gray whale distribution in summer (July-August) and autumn (September-October). Transect sightings (tSI) only; sample sizes listed in Table 2.

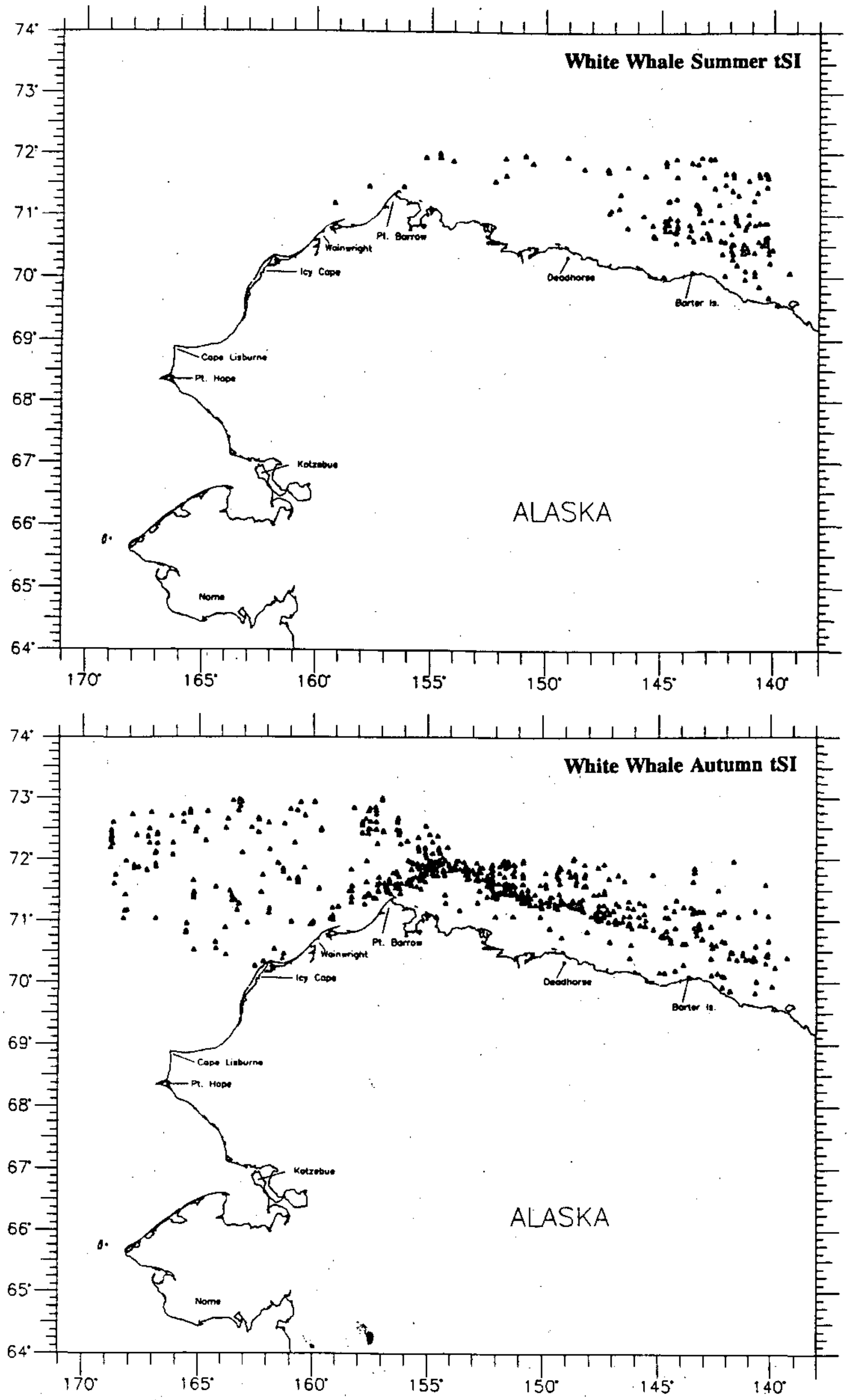


Figure 6. White whale distribution in summer (July-August) and autumn (September-October). Transect sightings (tSI) only; sample sizes listed in Table 2.