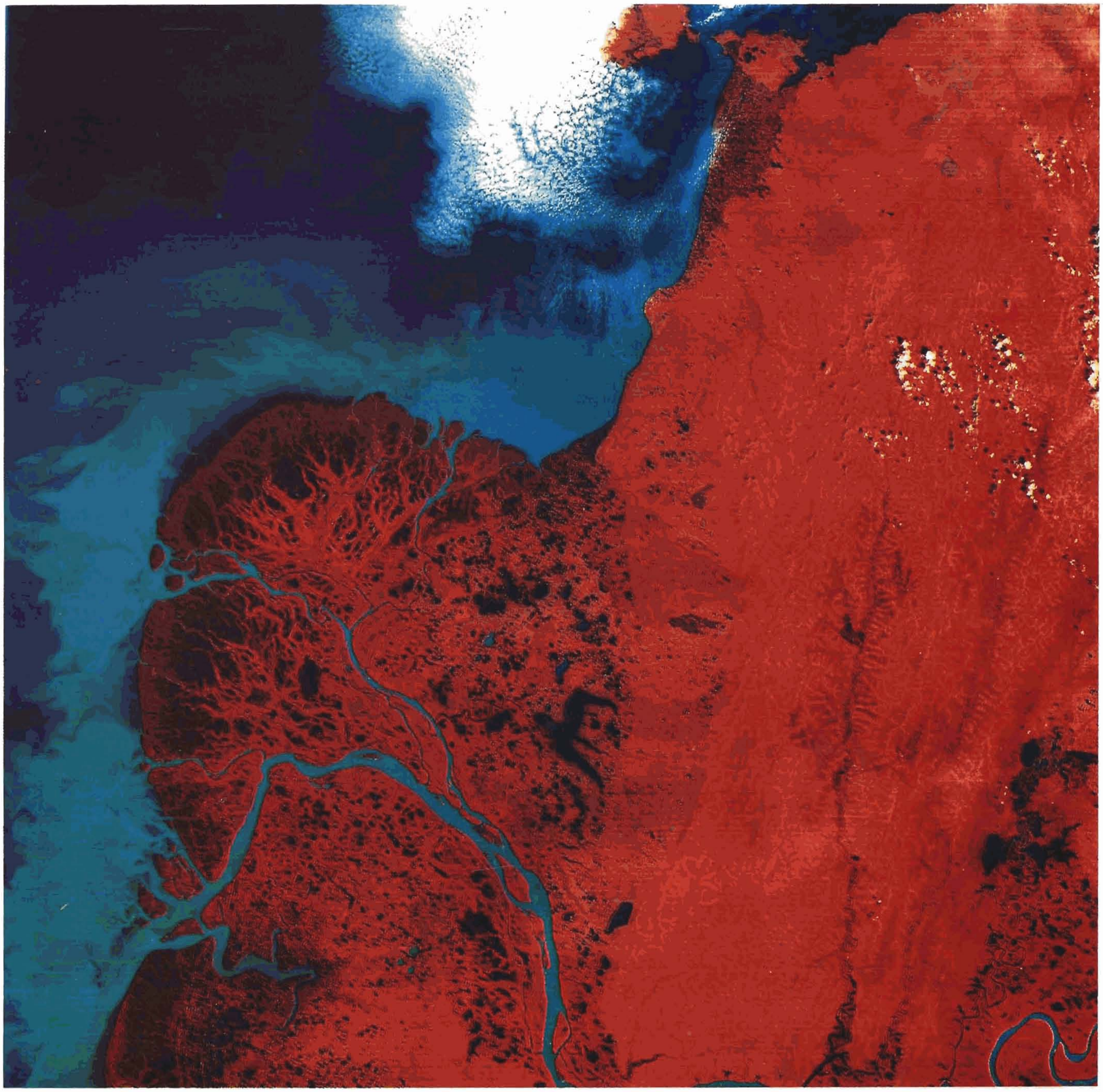
Outer Continental Shelf Environmental Assessment Program

The Yukon Delta



A Synthesis of Information

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NOTICES

Cover: Landsat™ image of the Yukon Delta taken on July 22, 1975, showing the thermal gradients resulting from Yukon River discharge. In this image land is depicted in shades of red indicating warmer temperatures versus the dark blues (colder temperatures) of Bering Sea waters. Yukon River water, cooler than the surrounding land but warmer than marine waters, is represented by a light aqua blue.

The Yukon Delta
A Synthesis of Information

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Abstract

This report provides a synthesis of environmental information on the Yukon Delta, primarily using results from studies conducted since 1983. The synthesis characterizes the major physical properties and resources of the Yukon Delta and identifies regional trends in biological use of major habitats.

The Yukon Delta provides important seasonal habitat for numerous species of migratory birds, fish, and some marine mammals. The delta is characterized as a "pass-through" system or exporting-type estuary, where physical processes (river flooding, ice transport, coastal currents, and tidal mixing) and biological processes (metabolism and migration) annually remove wetland energy reserves (plants, invertebrates, and fish). The majority of river-borne particulate matter and dissolved nutrients are transported offshore with the Yukon River plume into the inner shelf waters of the northern Bering Sea. Juvenile salmon residence in the nearshore habitats is brief. Most salmon smolts appear to be carried 20 to 30 km offshore to the delta front by strong river currents during periods of outmigration. The delta front and inner shelf waters of Norton Sound might function as an "offshore estuary" for salmon by providing an area for the juveniles to physiologically adapt to the marine environment.

Coastal mudflat and slough habitats are intermediate transition zones between terrestrial and estuarine/marine systems and might provide important areas for nutrient cycling and processing within the Yukon Delta. Calculation of waterbird energy requirements indicates an increase in the importance of coastal mudflats in the fall to swans, dabbling ducks, and shorebirds through providing an easily accessible source of food in the form of plants and invertebrates.

Aquatic insects and meiofauna appear to be key components of deltaic food webs. They provide an abundant source of food for shorebirds and outmigrating fish at the appropriate times of the year when these higher organisms are present.

Preface

The Yukon River discharges its load of water and sediment into the Bering Sea by way of a flat, protruding extension of the western shore of Alaska known as the Yukon Delta. The delta is shared by another river system, the Kuskokwim. The combined Yukon–Kuskokwim Delta is massive, dominating the eastern shore of the Bering Sea. Phenomenal numbers of waterfowl and fish occur there seasonally, and have attracted humans and played a vital role in their lifestyles for thousands of years.

Archaeological excavations at Cape Denbigh indicate the presence of Eskimos in Norton Sound more than 4,000 years ago. The early inhabitants were nomadic, living in temporary camps and hunting for seals and small tundra mammals. Roughly 2,500 years would pass before fishing was integrated into their subsistence economy. With the advent of fishing, the nomadic lifestyle gave way to that of the modern Yupik culture. This lifestyle involves seasonal movements of families between semipermanent hunting and fishing "camps." Winter villages were centrally located between food gathering camps. Today, these villages are permanent communities along the lower Yukon River and the complex kinship and social relationships that have evolved remain the heart of the traditional Eskimo culture (Hemming et al. 1978; Wolfe 1981; Nunam Kitlutsisti 1982).

Navigational hazards in the Yukon–Kuskokwim Delta coastal environment are extreme and are responsible for the region remaining largely "unexplored" for much of the nineteenth century. Even today, it is a region of few people and among Alaska's most remote. Inhabitants are mostly of Yupik descent and live in small isolated villages of 100–500 people. On the Yukon Delta these villages are located primarily along the lower 62 km of the Yukon River. The intricate Yupik partnership between "land and man" is intact and is illustrated by the geographic and economic orientation of the people relative to the river and its salmon resources (Wolfe 1981). In most families annual cash incomes are earned in commercial salmon fishing and supplemented by subsistence activities involving plant materials, fish, mammals, and waterfowl. It is fitting that these Yupik Eskimos refer to themselves as the Kwikpagmiut, "people of the big river" (Wolfe 1981). The name reflects an acknowledgment by the Yupik of the great societal link between the people, the river, and the living resources of the Yukon Delta.

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Chapter 1

Introduction

1.1 REGIONAL SETTING

The Yukon River is the longest river in Alaska and the fourth largest in the United States. Its headwaters are located in Canada at Marsh Lake, British Columbia, some 3,200 km upriver from the Bering Sea. The river is famous for its large runs of chinook salmon and their remarkable long-distance migrations to inland spawning grounds. For some stocks these are found hundreds of miles upstream in interior Alaska and Canada's Yukon Territory.

In western Alaska, a single massive delta (1.295×10^5 km^2) has formed at the mouths of the Yukon and Kuskokwim rivers. The Yukon–Kuskokwim Delta is rivaled in size in North America only by the Mississippi Delta, which varies between an area of 3.24×10^4 km^2 and 1.22×10^5 km^2 (U.S. Dep. Commer. 1985). The Mackenzie Delta, another arctic delta, is also impressive at about 6.52×10^3 km^2 (Fairbridge 1968).

The Yukon River drains an area of slightly less than 9×10^5 km^2, which represents nearly half of the total drainage basins of Alaska. The river has a mean annual water discharge rate of 6,000–7,000 m^3/s. Its sediment load has been estimated at $70\text{–}90 \times 10^6$ t/yr, or roughly 90% of all sediments entering the Bering Sea (Czaya 1981; Larsen et al. 1981). By comparison, the entire Mississippi River system (third longest river and seventh largest drainage basin in the world) has a drainage area of 3.2×10^6 km^2, representing approximately one-third of the total drainage area of the contiguous United States. The Mississippi River has an average discharge rate of 17,300 m^3/s with an average annual suspended load of 312×10^6 t/yr. River drainages comparable to the Yukon River in terms of size, discharge, and sediment load are listed in Table 1.1.

1.2 RESEARCH OVERVIEW

Since its inception in 1974, the Outer Continental Shelf Environmental Assessment Program (OCSEAP) has administered a large body of oceanographic research designed to measure and characterize the major environmental components and processes of the Alaskan Outer Continental Shelf (OCS). Environmental research prior to oil and gas exploration and development on continental shelves of the United States is mandated by the OCS Lands Act of 1953 as amended in 1978 (U.S. Dep. Inter. 1981*a*). In the northern Bering Sea, OCSEAP research has resulted in the only information upon which issues related to planned OCS activities have been evaluated.

The results of OCSEAP and other pertinent research in Norton Sound have previously been made available in various synthesis documents (Hood and Calder 1981; Zimmerman 1982; Truett et al. 1984; Truett and Raynolds 1984; Truett 1985). This information is also contained in Environmental Impact Statements prepared for OCS Sales 57 and 100 (U.S. Dep. Inter. 1982, 1985). The synthesis documents were designed to provide accurate descriptions of the physical and biological environments of Norton Sound likely to be affected by scheduled OCS lease sales. Discussions focused on recent research results and the possible environmental consequences of offshore oil and gas development in Norton Sound, and indicated areas where additional information was needed.

During 1980, OCSEAP synthesis and Bureau of Land Management (BLM) "scoping" efforts examined the environmental issues of OCS Sale 57 in Norton Sound (U.S. Dep. Inter. 1981*b*; Zimmerman 1982). One outcome of these public forums was the identification of the Yukon Delta as an area or "habitat" of special concern. This concern stemmed in large part from the delta's closeness to prospective lease tracts and a general lack of information from this area. Four broad categories of questions were expressed concerning the adequacy of existing information in socioeconomic, oceanographic (physical and biological), and technological disciplines:

1) ***Protection of Cultural Lifestyles.*** If lower Yukon River villages are to function as service bases for the petroleum industry, how would the OCS sale proposal affect (a) patterns in regional and community demography; (b) local costs for goods and services, primarily fuel; (c) village tax bases; (d) local hire; and (e) village crime rates? If commercial quantities of oil were discovered in Norton Sound,

TABLE 1.1—Size and average annual discharge rates and sediment loads of large North American rivers (van der Leeden 1975; Milliman and Meade 1983).

River	River length (km)	Drainage area (10^3 km^2)	Discharge rate (m^3/s)	Sediment load (10^3 t/yr)
Yukon	3,200	900	6,500	80
Mackenzie	4,241	1,798	7,840	100
St. Lawrence	4,000	1,275	14,000	4
Missouri	3,185	1,600	1,940	218
Columbia	1,954	1,429	7,168	8
Frazer	1,118	236	3,164	20

how would "boom-related" increases in infrastructure be supported in the future?

2) ***Effects of OCS Development on Fish and Wildlife Resources.*** The protection of subsistence resources, commercial fisheries, and wildlife habitats was of paramount concern. Is the existing information adequate to describe which biological resources are at risk from possible oil spills? Nearshore fish and Yukon Delta waterbird populations were of particular interest. Does the available information adequately describe seasonal patterns of habitat use by the dominant delta species? Will gravel be needed from the Yukon Delta for offshore development? If so, from where, and with what impact on biological habitat? Should an offshore buffer zone (32 km) be established around the Yukon Delta to protect the coast from possible oil spill impacts?
3) ***Physical Processes.*** Many questions concerned the ability of existing models to accurately describe nearshore circulation of the Yukon Delta. Great concern was expressed regarding the apparent lack of information on coastal transport processes. It was believed that physical data were needed from the nearshore waters surrounding the Yukon Delta to realistically predict biological implications of possible oil spills. How much is the nearshore circulation influenced by coastal forcing processes, including sea breezes, river runoff, and marine intrusions?
4) ***Available Technology.*** Does the petroleum industry possess demonstrated technology capable of withstanding regional seismic and geotechnical hazards, superstructure icing, and wave forces? Have oil spill contingency plans for Norton Sound and the Yukon Delta been developed? How will important habitats and populations be protected from damage in the case of a major oil spill?

Clearly, there was an overwhelming perception that coastal impacts resulting from offshore oil and gas development in Norton Sound would be more than transitory and would effect lifestyles on the delta. These concerns are noteworthy; they are diverse in topical coverage, yet similar in the desire to ensure the well-being of a citizenry so dependent on wilderness resources. The questions addressed a wide audience, including coastal zone and resource managers, and the petroleum industry itself. Not all issues were in the purview of OCSEAP, but those in the oceanographic realm had a significant effect on the direction future "ecosystem" research would take. In this context, it is necessary to acknowledge other organizations conducting studies on the Yukon-Kuskokwim Delta. It is from their efforts and data sets that many of the concepts put forth herein have been made possible.

The U.S. Fish and Wildlife Service (USFWS) manages the Yukon Delta National Wildlife Refuge. This refuge, established in 1980, encompasses more than 26 million acres of land and water on the Yukon–Kuskokwim Delta. A comprehensive refuge plan identifying the USFWS's responsibilities, activities, and directions for the refuge was completed in 1988 (U.S. Dep. Inter. 1987, 1988). A major purpose of the Yukon Delta Refuge is "to conserve fish and wildlife populations and habitats in their natural diversity including, but not limited to, shorebirds, seabirds, whistling (tundra) swans, emperor, white-fronted and Canada geese, black brant and other migratory birds, salmon, musk-ox, and marine mammals." Fishery research and management plans have objectives to conserve populations and fulfill international treaty obligations.

The State of Alaska, through the Alaska Department of Fish and Game (ADFG), is responsible for managing the commercial salmon fisheries of the Yukon River. The ADFG is an excellent source of information on fishery statistics including age, sex, size composition, run timing, and spawning areas for chum and chinook salmon. Current State and Federal coordinated salmon research is focusing on the stock compositions of chum and chinook salmon harvested in domestic and Canadian fisheries.

In 1983 the National Science Foundation (NSF) funded a pilot study to examine organic matter cycling and transport in the northern Bering Sea. This research, called ISHTAR (Inner Shelf Transfer and Recycling), was premised on the hypothesis that biological production in the coastal waters of Norton and Kotzebue sounds would be most influenced by land-derived nutrients from the Yukon River. In the southeastern Bering Sea, NSF-funded PROBES (Processes and Resources

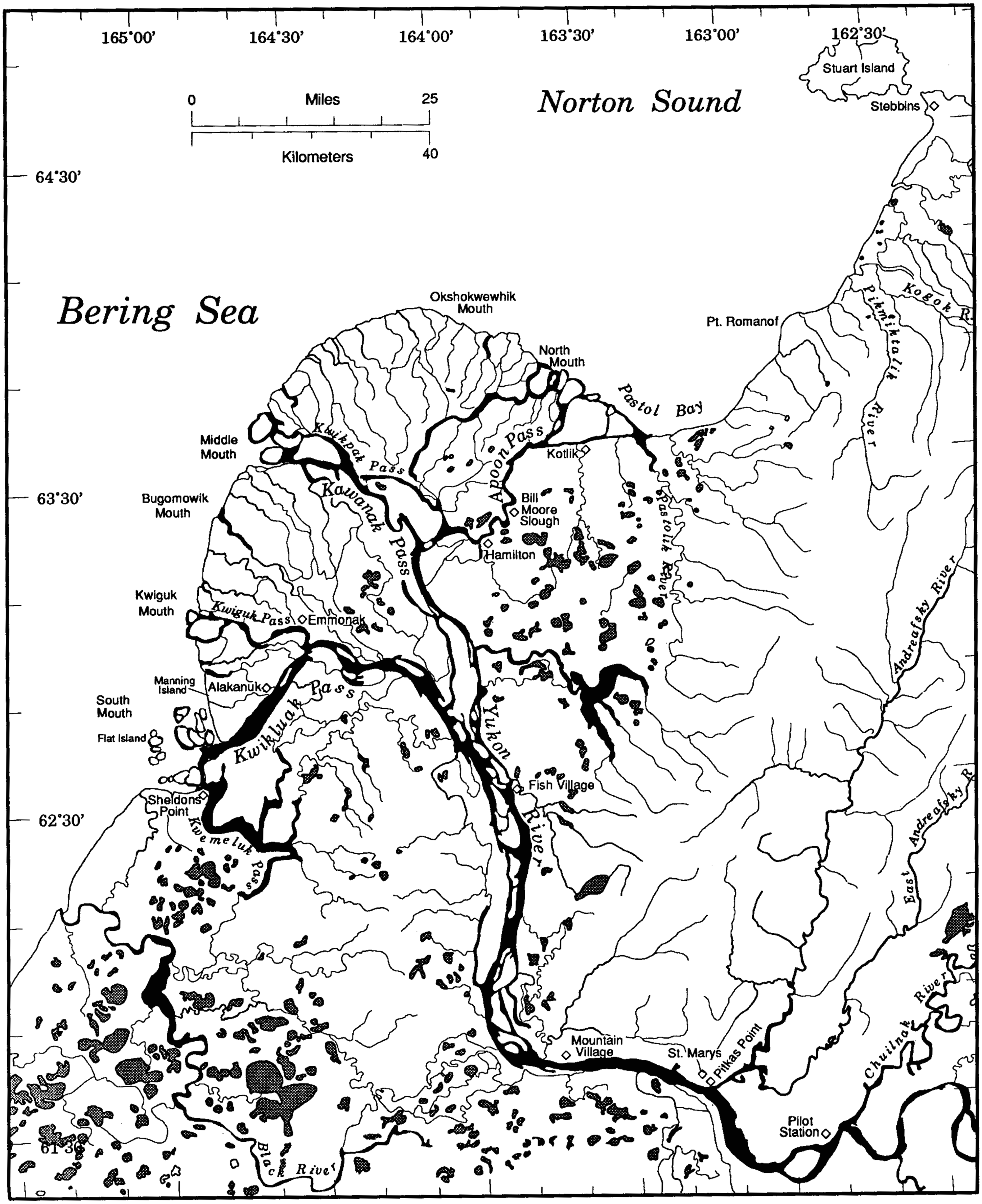

FIGURE 1.1—The Yukon Delta, Alaska.

of the Bering Sea Shelf) research had previously demonstrated the spring bloom to be nitrogen-limited. ISHTAR investigators hypothesized that the Yukon River, with a nitrate content of 10 μM/liter, would sustain production throughout the summer (McRoy 1985). Although this hypothesis has since been discarded, ISHTAR is an ongoing effort that continues to examine annual variability in nutrient transfers through the western Bering Strait.

This report provides a synthesis of environmental information on the Yukon Delta. The results of recent OCSEAP research are emphasized although many other information sources have been consulted. The report is primarily concerned with new information that has been gained about the delta's ecology since 1983. From the OCSEAP perspective, this has included studies providing (1) environmental mapping of the region's sensitivity to spilled oil; (2) literature review and evaluation of research priorities relative to OCS oil and gas leasing; (3) information on regional transport processes and results of numerical modeling; (4) information on fish distribution, abundance, and habitat use of lower Yukon River habitats; and (5) information on seasonal use by birds, particularly waterfowl, of the deltaic vegetated intertidal zone and coastal waters. The major objective of the synthesis is to characterize the major physical properties and resources of the Yukon Delta and to identify regional trends in biological utilization of major habitats. An equally important objective is to describe, to the extent possible, how the dominant physical processes affect generalized use patterns. In conclusion, we offer our impressions of research needs for the Yukon Delta and immediate Norton Sound region resulting from this analysis.

Discussions in this report focus on patterns of animal use in three major habitats: (1) the estuarine coastal zone, (2) the lotic component, and (3) the lentic component of the Yukon River floodplain. The coastal habitat extends from the shoreline to the offshore delta front. The lotic habitat consists of the flowing water portions of the lower Yukon River; e.g., the main river channels. The standing waters of the delta, including lakes, backwater sloughs, or other semipermanent waters characteristic of the lower Yukon River, are the lentic habitat. Within each of these broad habitats further partitioning has been conducted when the data allow. Accordingly, several individual "habitat types" will be described as they pertain to dominant species or ecological groups. Discussions pertaining to the use of lower Yukon River habitat have been guided by the general precepts of the River Continuum Concept (Vannote et al. 1980; Minshall et al. 1985; Statzner and Higler 1985).

1.3 STUDY AREA DESCRIPTION

The OCSEAP study area encompasses the prograding portion of the Yukon Delta north of Cape Romanzof to the southwestern limits of Norton Sound. The coastline perimeter of this area is about 200 km (Fig. 1.1). The study area extends downstream from Pitkas Point, over the entire delta region, and into the nearshore regions surrounding the delta some 30 km offshore.

The Yukon Delta is a wide expanse of meandering waterways and innumerable lakes, with interstitial land dominated by willows and other tundra vegetation. The delta is dominated by a broad main river channel and many side sloughs and oxbow lakes. From the upriver boundary westward, the Yukon River floodplain is one of little apparent topographic relief. The emergent delta zone extending between Point Romanof and the Black River is a gently sloping plain (1:5,000) with active and abandoned distributary channels, channel bars, natural levees, interdistributary marshes, and lakes (Dupré 1980). Seaward of this, the delta platform has a less gentle slope (1:1,000) and water is typically shallow (about 3 m) as far offshore as 30 km. Beyond this is the steeper delta front, which connects to the prodelta that extends up to 100 km offshore (Dupré 1980).

Prospective OCS lease offerings in Norton Sound have been located within 12 km of the northern Yukon Delta (Fig. 1.2). It is also possible that oil development could occur within State of Alaska waters or on native corporation deltaic land claims (State of Alaska 1982; Zimmerman 1982).

1.4 LITERATURE REVIEW

In 1983 a dedicated effort was made by Truett et al. (1984) to seek out, analyze, and synthesize all relevant environmental information for the Yukon Delta. This work objectively highlighted research needs and priorities for the delta ecosystem relative to offshore leasing in Norton Sound. Three major research needs were identified, and included studies to describe (1) the seasonal occurrence and use of estuarine habitats by fish, (2) the seasonal use of deltaic habitats by migratory waterbirds, and (3) coastal circulation of the delta. In the latter instance, three physical processes were identified as being especially important for predictive assessment of impacts on biological resources. These included (1) storm surge frequency and magnitude, (2) dynamics and magnitude of salt wedge intrusions into delta distributary channels, and (3) three-dimensional circulation and

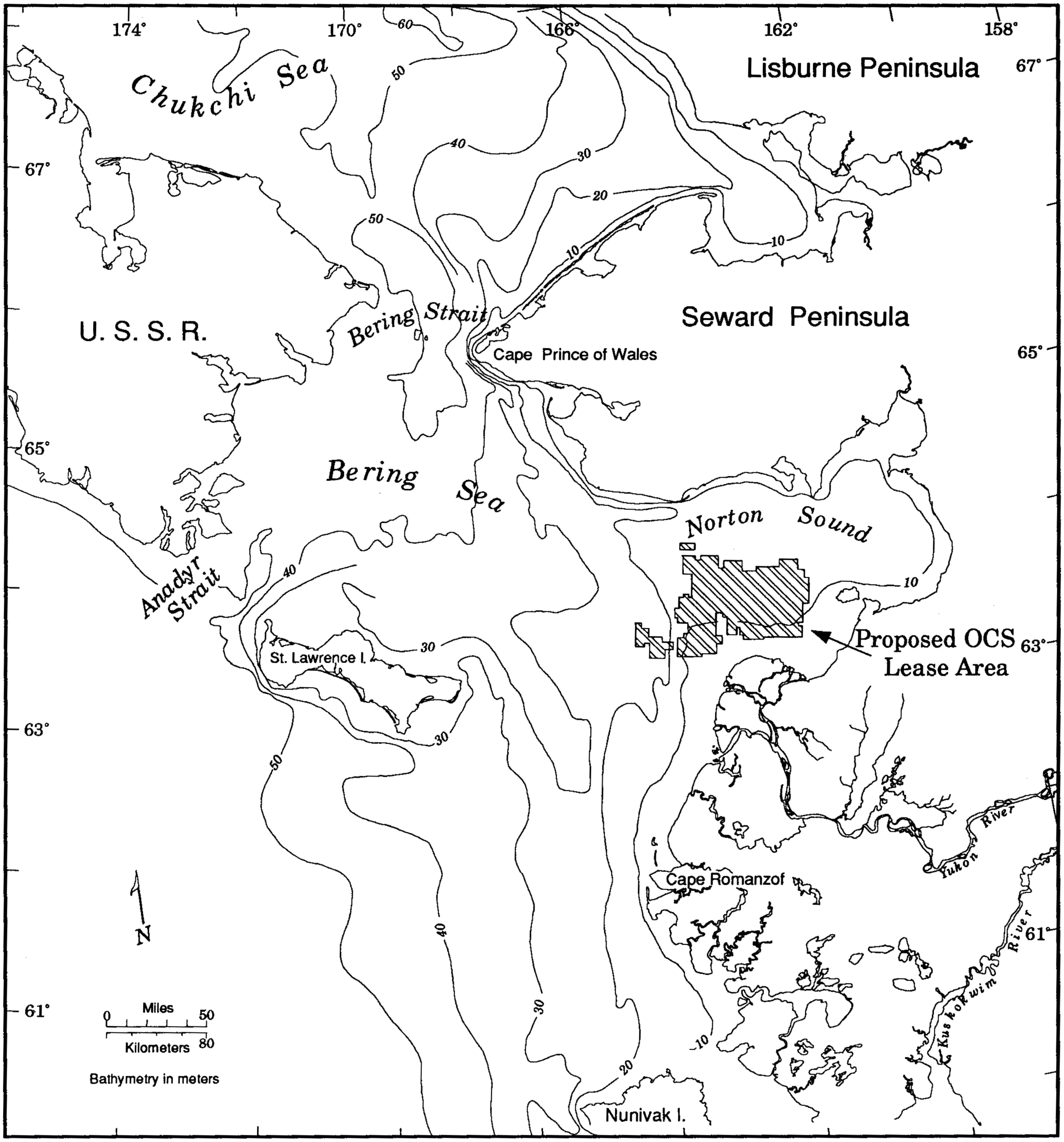

FIGURE 1.2—Location of proposed OCS oil and gas leasing in Norton Sound.

transport patterns in the shallow waters of the delta platform.

Truett et al. (1984) used a systems approach to summarize the existing information on community structure and energy transfers in terrestrial/freshwater, estuarine, and marine portions of the Yukon River study area. In freshwater, or aquatic, habitats, birds were considered to be the primary vertebrate constituents. In truly aquatic portions of the study area the food chains were characterized as short and simple; that is, with most animals feeding directly on emergent and terrestrial vegetation, with no intermediate links.

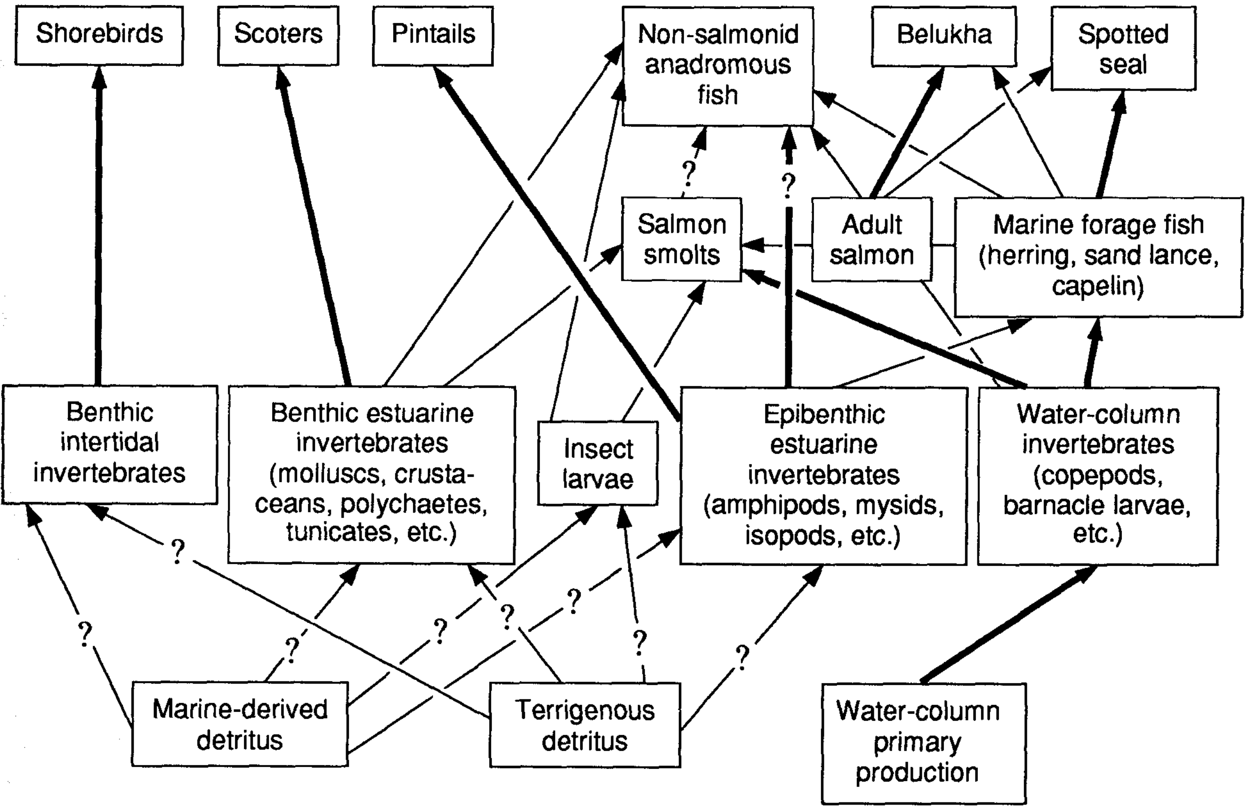

FIGURE 1.3—Generalized estuarine food web of important species in the vicinity of the Yukon Delta. Note that "estuarine" habitat extends several tens of kilometers seaward of the delta coast and inland up river distributaries. Arrow widths represent relative importance of food sources to consumers; ? represents major uncertainties. (Adapted from Truett et al. 1984.)

The estuarine food web was more complex and was strongly affected by seasonal patterns of animal migration. The estuarine zone was defined as extending seaward to the limits of the influence of the Yukon River. It was noted that the prey base was varied and the carbon sources unclear, although primary production in the water column and benthic detritus of terrestrial origins were indicated (Fig. 1.3). Relying on similar observations from other Alaskan estuaries, Truett et al. (1984) speculated that birds and fish depend largely on epibenthic and benthic invertebrate foods common to a shallow-water benthos fueled by detritus. The marine system was characterized by marine fish and mammal presence in open waters, where biological production was associated with nutrients of terrigenous and marine origins. The relative abundance and contributions of organic matter, nutrients, and trace elements to coastal environs from Yukon River "outwelling" (Nixon 1980), *in situ* primary production, and marine intrusions were not known.

As mentioned above, the Truett et al. (1984) synthesis of information for the Yukon Delta identified research needed to understand the area's biophysical environment. Between 1984 and 1986 OCSEAP launched a series of surveys that have provided new data on the dominant physical processes influencing the lower Yukon River and nearshore circulation. High priority was also given to inventories of fish and bird populations that could be impacted by oil pollution. Shoreline areas were studied, mapped, and rated with respect to sensitivity to oil spills and their capacity to recover. Finally, with the aid of hydrologic data collected at Kobolunuk, Alaska, OCSEAP's existing oil spill trajectory model for Bering Sea shelf waters (Liu and Leendertse 1987) could, if needed in future risk assessments, be adapted to the Yukon Delta.

The results of OCSEAP-sponsored research are contained in numerous technical reports and papers. Their complete citation can be found in the *OCSEAP Comprehensive Bibliography* (U.S. Dep. Commer. 1988).

Chapter 2

The Physical Environment

2.1 GEOMORPHOLOGY

The Yukon Delta is a depositional plain that has built rapidly seaward since the sea reached its present level about 5,000–6,000 years ago (Nelson and Creager 1977). This plain is gently sloping, with active and abandoned distributary channels and channel bars, natural levees, interdistributary marshes, and lakes (Dupré 1980). The bottom slope is so gentle (about 1:1,000) seaward of the emergent edge of the delta that as far as 30 km offshore, water depths do not exceed 3 m. Beyond this gently sloping sub-ice platform is the delta front, which is steeper (1:500), and water depths increase from 3 to 14 m. Beyond the delta front is the prodelta, with less slope (1:2,000), extending up to 100 km offshore (Dupré 1980).

The modern Yukon Delta is a relatively young geologic feature, having formed within the past 2,500 years as the river course shifted to where it presently enters Norton Sound (Dupré 1978). Both the emergent and submerged (delta platform) portions of the delta (Fig. 2.1) contain three major distributaries (Kwikluak or South Mouth, Kawanak or Middle Mouth, and Apoon or North Mouth). These major distributaries bifurcate as they near the coast. Unlike most deltas, the major river distributaries continue offshore after bifurcation. These offshore extensions of the distributaries are one-half to one kilometer wide and 5 to 15 m deep. They may extend as far as 30 km beyond the shoreline.

The channels have a low to moderate sinuosity and exhibit considerable lateral migration. Migration is seen in the formation of underwater point bar deposits. Shifting depositional environments have resulted in an upwards fining of sediments in the upper 15 m of seafloor. This layering can be characterized as an erosional channel base overlain by moderately sorted, fine to very fine sand grading upwards to moderately sorted sand and silty sand deposited on subaqueous levees. Satellite imagery suggests that bedload transport occurs in these channels throughout most of the summer. The channels may also serve as conduits for sub-ice currents during the winter months (Dupré and Thompson 1979).

Substrates on both emergent and submerged portions of the Yukon Delta are depositional and less than 2,500 years old (Dupré 1980). Permafrost appears to be present, though discontinuous and relatively thin (2–3 m), in many areas of the delta region (Dupré 1978). It may not be present along large streams and rapidly prograding coastlines and is almost certainly nonexistent, or thin and discontinuous, in subsea delta sediments (Dupré 1980). Burns (1964) reported the occasional presence of pingos in the delta plain.

Substrates in the emergent portion of the delta are composed of various assortments of sands, silts, and clays. River channel and bar deposits are typically well-sorted and silty sands. Organic matter and small-sized sediment particles predominate in less swiftly moving waters away from the main river channels. Poorly sorted silt, mud, and organic detritus are common on natural levees, meander swales, and other between-distributary environments.

At the margin of the emergent delta, tidal flats typically extend 100 to 1,000 m offshore. The substrates of the flats range from poorly sorted sandy silts in low-energy environments (e.g., on the northern side of the delta) to moderately and poorly sorted silty sand in areas of higher wave energy (such as on the western side of the delta). Sediment deposits on tidal flats are generally finer than benthic substrates farther offshore (Dupré and Thompson 1979). The former deposits also contain larger amounts of organic detritus, and are subject to more extensive bioturbation in their top few centimeters.

2.2 PHYSICAL PROCESSES

2.2.1 Meteorology

The climate of Norton Sound, including the Yukon Delta, is primarily influenced by arctic and continental air masses from the north and east in the winter, and by maritime air masses from the Pacific Ocean in the summer (Overland 1981). In winter (from September to May), the atmospheric pressure regime from the northern Pacific and Arctic Oceans is most frequently characterized by low pressure systems lying

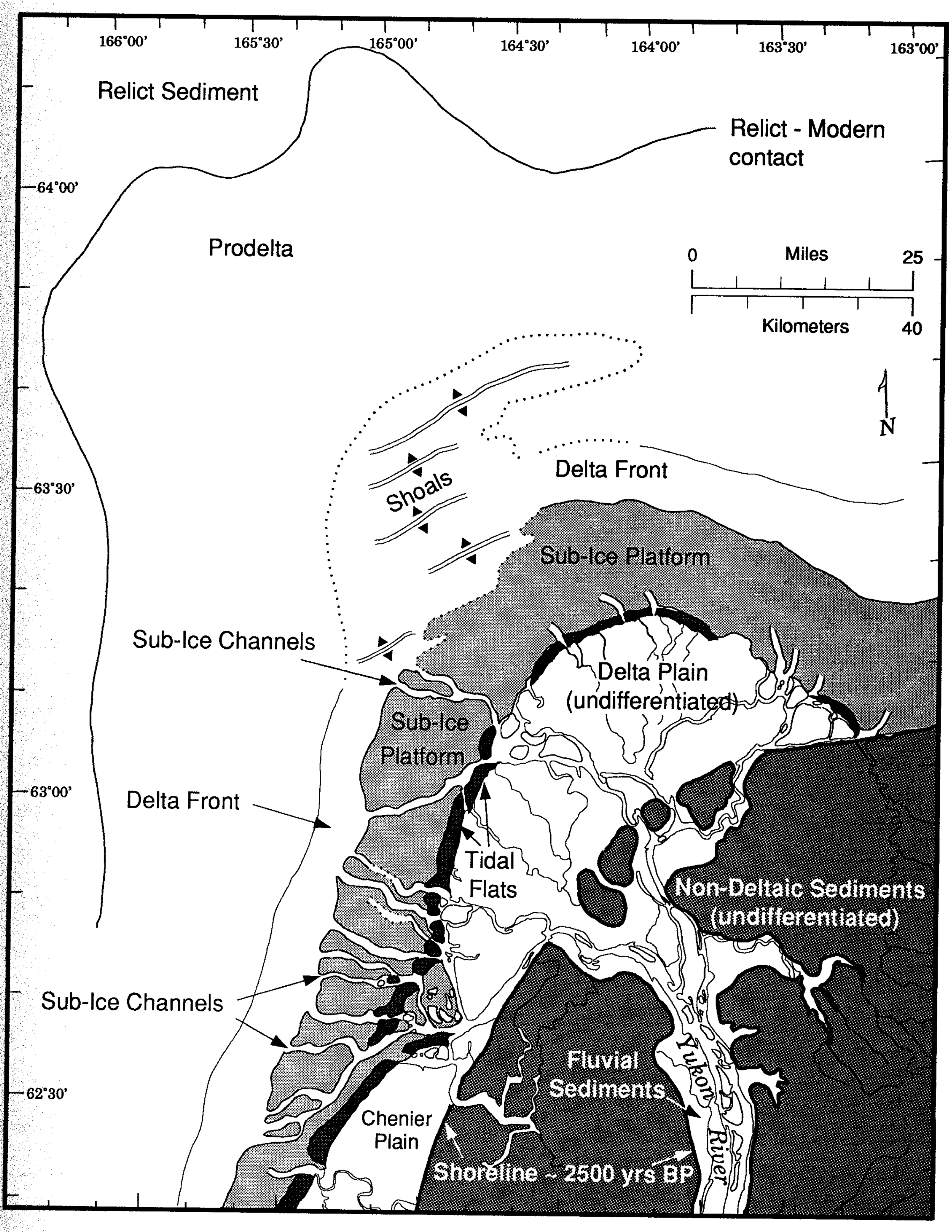

FIGURE 2.1—Depositional environments of the Yukon Delta. (Adapted from Dupré 1980.)

over the Bering Sea and high pressure systems in the Chukchi Sea (Barry 1979). The low pressure systems generally move to the east along trajectories in the vicinity of the Aleutian Archipelago; however, these weather systems occasionally travel northeast through the Bering Sea. Although the high pressure systems tend to be stationary, when they do move they are often displaced to the south or southwest.

The atmospheric pressure regime is seasonally most variable in summer. Low pressure systems are usually found overlying the area extending from the northeastern Bering Sea to the eastern Beaufort Sea. Along the coast of the northeastern Bering Sea and Norton Sound, surface winds are more frequent from the northeast from September through May. However, the eastern part of Norton Sound is characterized by frequent easterly winds (Brower et al. 1977). Southwesterly to southeasterly winds are more frequent during the summer (June–August). Wintertime wind speeds generally range from 4 to 11 m/s (8 to 21 knots), while summertime wind speeds range from 4 to 9 m/s (8 to 18 knots). Wind speeds of more than 21 m/s (41 knots) occur infrequently, less than 15% of the time.

Mean monthly air temperatures on the Yukon Delta range from a high of 10°C in July and August to a low of −14°C during the winter months (Table 2.1). From June through September, extreme temperatures can range from −1 to +18°C (Brower et al. 1977). This range may underestimate actual temperature extremes, as McDowell et al. (1987) observed a high temperature of 27.8°C at St. Marys in mid-July 1985.

Barometric pressure in the delta region is primarily governed by the large-scale pressure field that dominates the Bering Sea and Gulf of Alaska. Between September and April, low pressure centers are commonly located over the Aleutian Islands, in Bristol Bay, and in the Gulf of Alaska. Monthly mean pressures on the delta range from 1,004 to 1,014 mbar. During the summer, the large-scale pressure system relaxes, but mean monthly pressures on the delta remain between 1,009 and 1,013 mbar. These values are not representative of the extremes that can be experienced during storm events.

The large-scale wind field is also governed by the low pressure system that normally lies near the Aleutian Islands. Mean monthly wind statistics from Unalakleet and Cape Romanzof (Table 2.2) illustrate very steady conditions except during summer months. At Unalakleet, easterly winds prevail from September through May and scalar mean speeds range from 4.2 to 6.9 m/s. At Cape Romanzof, prevailing winds from September through June are from the northeast. During this period, scalar mean winds at Cape Romanzof are slightly stronger (4.3–7.6 m/s) than at Unalakleet. At both sites, winds reverse direction and weaken slightly in the summer. Wind directions on the delta closely resemble those recorded at Cape Romanzof (predominantly southerly during summer). In all likelihood this reflects similarities in the environmental setting of each site relative to the coast and the Bering Sea.

TABLE 2.1—Monthly mean meteorological statistics for the Yukon Delta region computed from observations at Cape Romanzof, 1953–68, and Unalakleet, 1948–74 (McDowell et al. 1987).

	Air Temperature (°C)			Pressure
Month	Mean	Minimum	Maximum	(mbar)
Jan	−13	−31	+2	1,011.5
Feb	−14	−33	+2	1,009.6
Mar	−12	−31	+2	1,013.7
Apr	−6	−22	+5	1,012.5
May	+2	−11	+11	1,011.6
Jun	+7	−1	+14	1,012.5
Jul	+10	+3	+18	1,012.3
Aug	+10	+5	+16	1,009.0
Sep	+7	+1	+14	1,007.8
Oct	+1	−10	+8	1,004.0
Nov	−5	−18	+3	1,005.0
Dec	−14	−28	+1	1,008.6

Extreme wind speeds occur episodically on the Yukon Delta during the passage of extra-tropical storms. Such storms are more frequent during the latter part of fall, at which time they may occur as frequently as three to five times per month. Storm winds may cause severe coastal flooding of the delta.

Annually, the Yukon Delta typically receives about 51 cm of rain and 102–127 cm of snowfall. Daily, precipitation is observed on the delta almost 35% of the time. August is usually the wettest month, raining on average almost 60% of the days. Precipitation is at a minimum, 25% of the days, during winter. Similarly, maximum cloud cover occurs in August (75% probability on a given day) and minimum cover (40% probability) in February and March, when air temperatures are extremely low. Snowfall during the 9-month period from fall through spring occurs with a daily probability of roughly 15%.

The Yukon Delta coastal region is influenced by thermally driven mesoscale circulation (*coastal sea breezes*) during the summer. Zimmerman (1982) indicated that sea breezes can dominate the local meteorology 25% of the time in summer, and reach speeds up to 15 m/s (29 knots). Kozo (1982), describing coastal sea breezes occurring over a 20-km band

TABLE 2.2—Mean monthly wind statistics for the Yukon Delta region (McDowell et al. 1987).

	Unalakleet			Cape Romanzof		
Month	Scalar mean speed (kt)	Prevailing direction	Frequency (%)	Scalar mean speed (kt)	Prevailing direction	Frequency (%)
Jan	13.8	E	54	14.5	NE	27
Feb	13.1	E	48	14.8	NE	33
Mar	11.8	E	43	12.8	NE	28
Apr	9.8	E	30	13.3	NE	25
May	8.5	E	24	10.3	NE	27
Jun	8.3	SW	22	8.4	NE	23
Jul	8.7	W	20	8.0	SW	21
Aug	9.2	E	24	9.2	S	22
Sep	9.9	E	34	10.7	NE	28
Oct	11.0	E	42	11.4	NE	30
Nov	13.2	E	55	13.7	NE	29
Dec	12.5	E	53	14.5	NE	33

(centered on the coastline) along the Beaufort Sea (70°N), reported that arctic land–sea temperature differences that generate sea breezes are typically around 20°C. Moritz (1977) reported that the tundra–ocean thermal contrast at Barrow remains positive (land always warmer than water) in summer even though there can be as much as a 15°C drop in land temperature overnight.

Kozo (1984) used surface wind data from coastal stations at Northeast Cape, Unalakleet, and Nome to study the mesoscale meteorology of Norton Sound. Time series analysis of wind data revealed a significant peak on the clockwise component of the rotary spectra corresponding to a 1-day (diurnal) period characteristic of sea breezes. However, both clockwise and counterclockwise peaks appear on the Nome and Unalakleet spectra for the month of July. Kozo (1984) noted that the significant counterclockwise diurnal peaks seen in the Norton Sound data have not been observed elsewhere in arctic Alaska.

Meteorological data obtained from Kotlik and Emmonak by McDowell et al. (1987) were analyzed to describe the major characteristics of the delta sea breeze. Weather stations were located at Okwega Pass (8 km upstream) and Kwiguk Pass (14 km upstream) on the lower Yukon River. Each location was within the expected influence of the delta sea breeze and data were recorded over the summer between mid-June and mid-August 1986. Sea breeze periodicity and rotation were described through an analysis of the rotary wind spectra of the north and east velocity components of the delta wind field (McDowell et al. 1987). The rotary spectra for the Kotlik winds indicated significant peaks in both clockwise and counterclockwise diurnal components. Although this is different from what Moritz (1977) reported for other arctic sea breezes, it is substantiated by Kozo's (1984) observations of counterclockwise diurnal peaks in the rotary spectra of wind data from Unalakleet and Nome. The Kotlik wind data also suggest that coastal wind circulation in early July 1986 was controlled by the sea breeze. During this period, north–northwesterly to north–northeasterly onshore winds with maximum speeds of 7.5 and 7.7 m/s were frequently encountered.

2.2.2 Sea Ice

Sea ice surrounds the Yukon Delta during the winter months. The extent of the ice coverage is illustrated in maps contained within the *Alaska Marine Ice Atlas* (LaBelle et al. 1983). Sea ice is usually absent until about mid-October. By mid-November, there is a 40% probability that sea ice will be present at the delta front. Between mid-December and mid-April, ice is always present and ranges from 70 to 100% coverage. Shorefast ice extends much farther off of the Yukon Delta than other coastal segments in Norton Sound (Muench and Ahlnäs 1976; Ahlnäs and Wendler 1979). The more extensive shorefast ice coverage results from the shallow topography of the delta platform.

In deeper waters beyond the shorefast ice, sea ice persists until April or May. This ice primarily consists of loose pack ice with thicknesses of 0.7–1.2 m (Thor and Nelson 1981). Ice breakup in May is characterized by ice coverage of 50–60%. By mid-June or early July, the delta region is normally free of ice.

Little information is available regarding the icing of the lower Yukon River. Local inhabitants indicate that the cycle of river ice is nearly the same as that of sea ice.

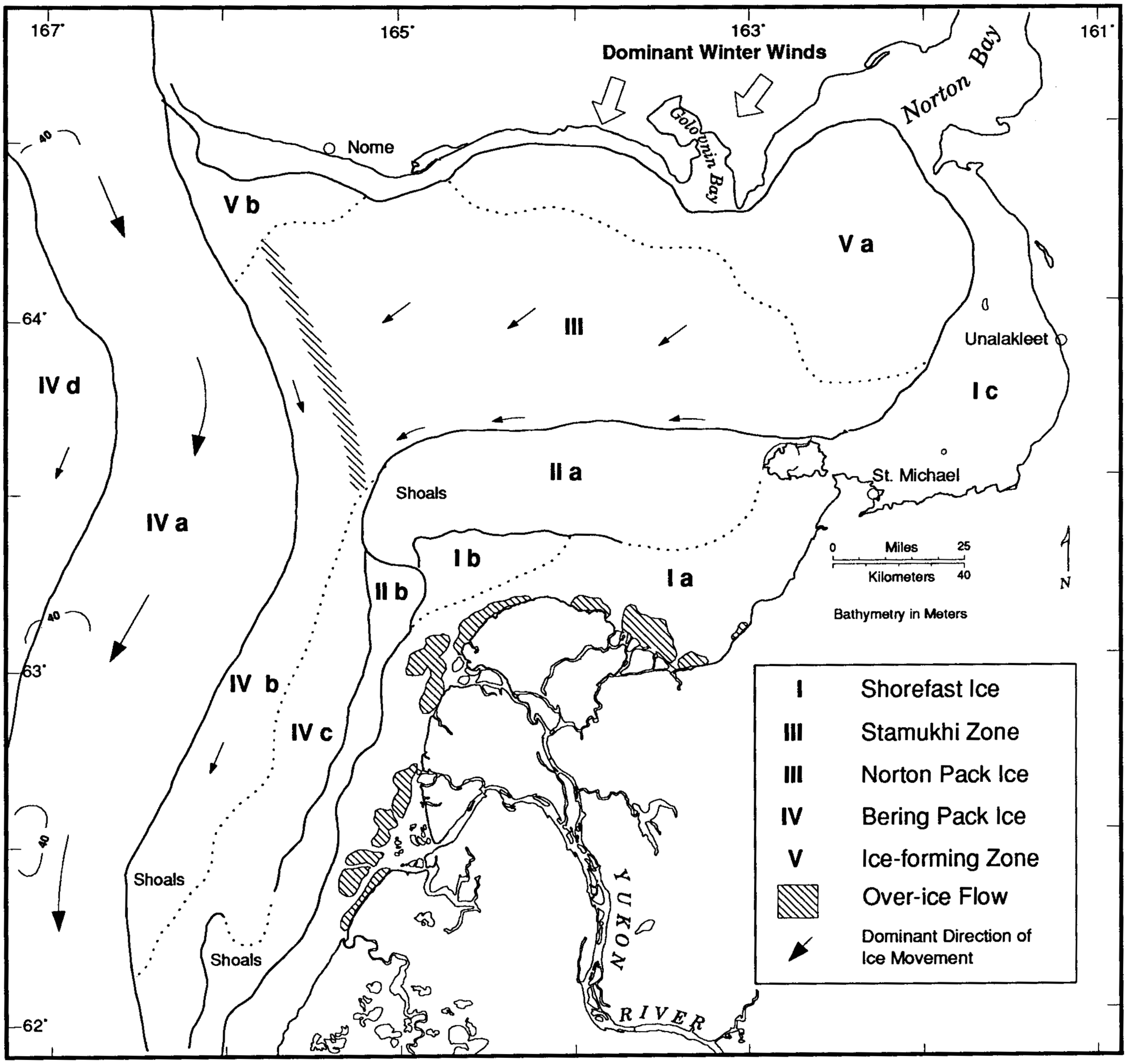

FIGURE 2.2—Late winter ice conditions in the Yukon Delta region. (Adapted from Dupré 1980.)

Truett et al. (1984), citing Dupré (1980), described the Yukon Delta ice regime as follows (not an exact quotation):

Freeze-up.—Ice begins to form along the shore in October as temperatures drop below 0°C. Bottomfast ice soon forms on intertidal mudflats and subaqueous levees, and the smaller sub-ice channels begin to be covered by floating shorefast ice. The larger sub-ice channels, which are extensions of main distributaries, continue to maintain a channelized flow of fresh water. They are the last of the nearshore areas to be covered with ice.

Shorefast ice expands farther offshore in November until it reaches its maximum width of 15–60 km. Its outer boundary approximates the outer boundary of the shallow sub-ice delta platform. Most of the shorefast ice is floating, and is separated from the bottomfast ice near shore by active tidal cracks along the 1-m isobath. Water flows upward through the tidal cracks and then freezes, forming a layer of ice over the inner delta platform.

Winter.—Beginning in early December, a relatively stable band of shorefast ice fringes seaward to the stamukhi zone (Fig. 2.2). Beyond this shear zone, where ridged and deformed ice predominate, there is seasonal pack ice. Because wind is predominantly from the north during winter, the pack ice in Norton Sound is forced southward against the shorefast ice surrounding the delta. This creates intense bottom gouging in the stamukhi zone.

Breakup.—Spring breakup in the delta typically begins in early May. It is marked by a tremendous increase in sediment and water discharge that results in ice jams, extensive inland flooding, and river bank erosion.

As the river discharge increases, floating ice begins to lift, both in the river and along the coast. The bottomfast ice begins to be flooded by over-ice flow. Some sediment is carried onto the sea ice, bypassing much of the delta platform. Much of the water and sediment is carried by the sub-ice channels that cross the sub-ice platform, to be deposited along these channels and in the delta front or seaward of the platform. The floating ice in the channels soon breaks up and moves seaward.

During breakup it is common for southerly winds to predominate and assist ice removal. Large pieces of floating shorefast ice break off and move offshore. Grounded ice can temporarily remain in some shallow water areas northwest of the delta. By June the shorefast ice is usually gone. It is during this early summer period that the distributary channels introduce an apron of sediment underwater over much of the delta platform and farther offshore.

2.3 HYDROLOGY

2.3.1 Yukon River Discharge

The Yukon River is one of the major rivers of North America. It is ranked 24th in the world, draining an area of approximately 855,000 km^2 with a mean water discharge of 6,220 m^3/s (Lerman 1981).

The discharge of the lower Yukon River has an annual cycle characterized by strong (maximum) flows in May or June, and relatively weak flows between December and April. Significant fluctuations in discharge have been observed within a few days, and major interannual variations are common. Ten-year averages of monthly mean discharge (Fig. 2.3), calculated from daily measurements taken at Pilot Station (upstream of Pitkas Point) by the U.S. Geological Survey since October 1975, illustrate the annual hydrograph of the lower Yukon River. Interannual variations in the monthly means are relatively small, whereas maximal and minimal daily discharges vary greatly from the monthly averages (McDowell et al. 1987).

Analysis of winter-collected flow data has demonstrated mean river discharge rates to be consistently less than 2,000 m^3/s between January and May (McDowell et al. 1987). Peak river discharges usually occur between mid-May and mid-June. An exception occurred in 1978, the driest year for which data are available, when peak flow occurred in early July. Although maximum daily discharges are typical of May, it is also a month of relatively low overall river discharge. Flow is minimal prior to breakup. In contrast, June represents the period of greatest annual discharge resulting from a gradual reduction in flow after the peak. This reduction, as observed in averaged monthly rates, continues monotonically until the following May.

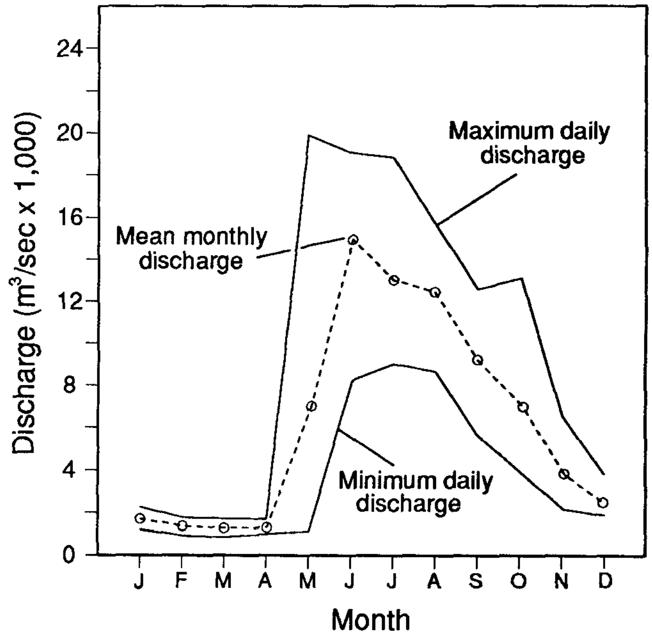

FIGURE 2.3—Annual hydrograph of Yukon River discharge at Pilot Station, 1975–86. Dashed line represents 10-year averages of monthly mean discharge estimates. Solid lines represent 1-day extreme discharges for each month. (Adapted from McDowell et al. 1987.)

McDowell et al. (1987) reported that river discharge rates are, on the average, most variable in August and September. An analysis of mean, maximum, and minimum discharge rates measured daily at Pilot Station between 1982 and 1984 shows a maximum flow in June followed by a less intense secondary peak in autumn. The secondary peak is most obvious in maximum daily discharge data for August and September (Fig. 2.4). The slight autumnal increase in discharge is thought to be a consequence of increased rainfall. Similar late summer increases in river discharge were

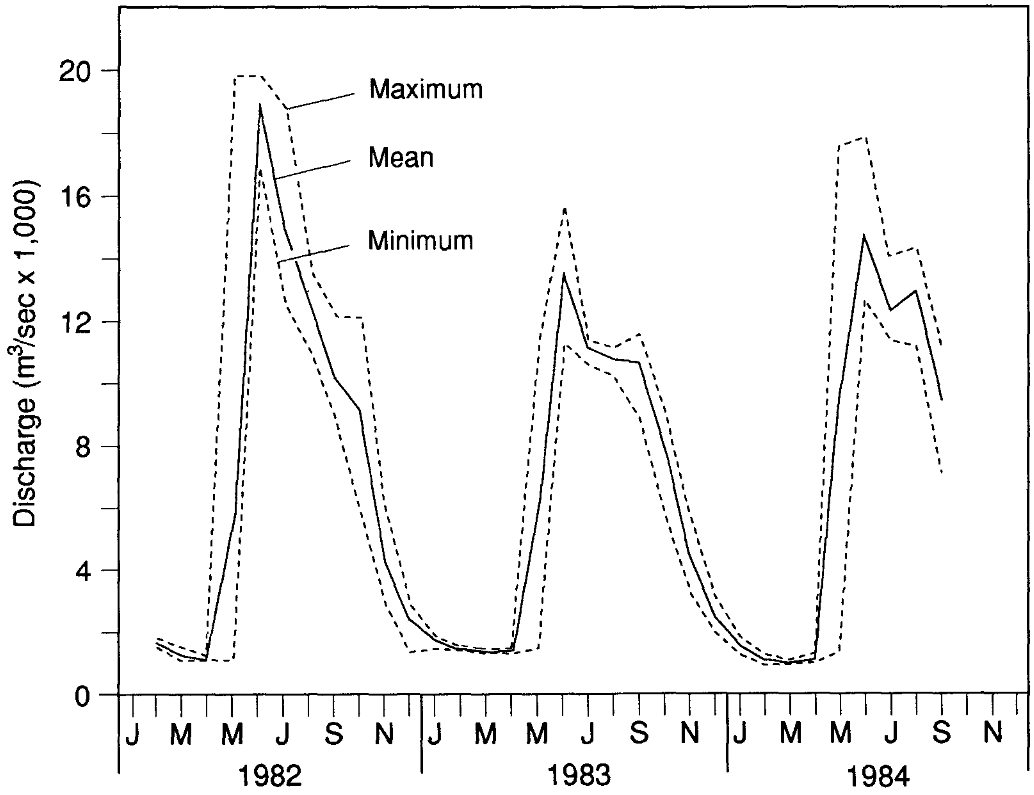

FIGURE 2.4—Seasonal variability in Yukon River discharge at Pilot Station, 1982–84. Solid line represents monthly mean values. Dashed line represents maximum and minimum 1-day discharge values for each month. (Adapted from McDowell et al. 1987.)

observed in 1985 and 1986 (Fig. 2.5). The high interannual variability in autumn discharge rates is exemplified in the 1985 data.

Discharge rates observed in the Yukon River during October 1985 exceeded those measured for September in all previous years for which data are available. For example, a discharge rate of 13,031 m^3/s was recorded on 1 October 1985. This is the highest daily discharge ever recorded in October. Similarly, average monthly discharge rates for December 1985 through February 1986 were the highest recorded since the mid–1970s. It is of interest that spring and summer conditions in 1986 were surprisingly similar to all other years. However, the discharge rates observed during that September were the highest on record. Such statistical presentations probably reflect the relatively short time series for which data have been recorded and may not be that anomalous.

Cross-sectional analysis of current velocity measurements in the lower Yukon River has indicated a partitioning of flow within the river's major distributaries (McDowell et al. 1987). The partitioning is described as being relatively independent of the total river discharge in summer during periods of increased flow (Fig. 2.6). In fall and winter, as the river level subsides, partitioning may vary due to the lower river's complex system of erosional channels. In general, downstream of the Head of Passes, the Yukon River distributes its water as follows: 66% through Kwikluak Pass, 26% through Kawanak Pass, and 8% through Apoon Pass (McDowell et al. 1987).

2.3.2 Storm Surges

A storm surge results when weather phenomena produce a variation in sea level relative to tidal height alone. Storm surges frequently result from the nearby passage of a storm. Because of its shallow water depths, long fetch, and low shore relief, the Yukon Delta is susceptible to storm surge inundation during ice-free months. During the summer and fall, storms typically approach Norton Sound from the southwest, generating strong southerly winds which, as the storm progresses to the north or northeast (the typical storm track), veer into the southwest and west. The large wind-generated waves produced by this sequence of wind shifts, superimposed on the positive surge

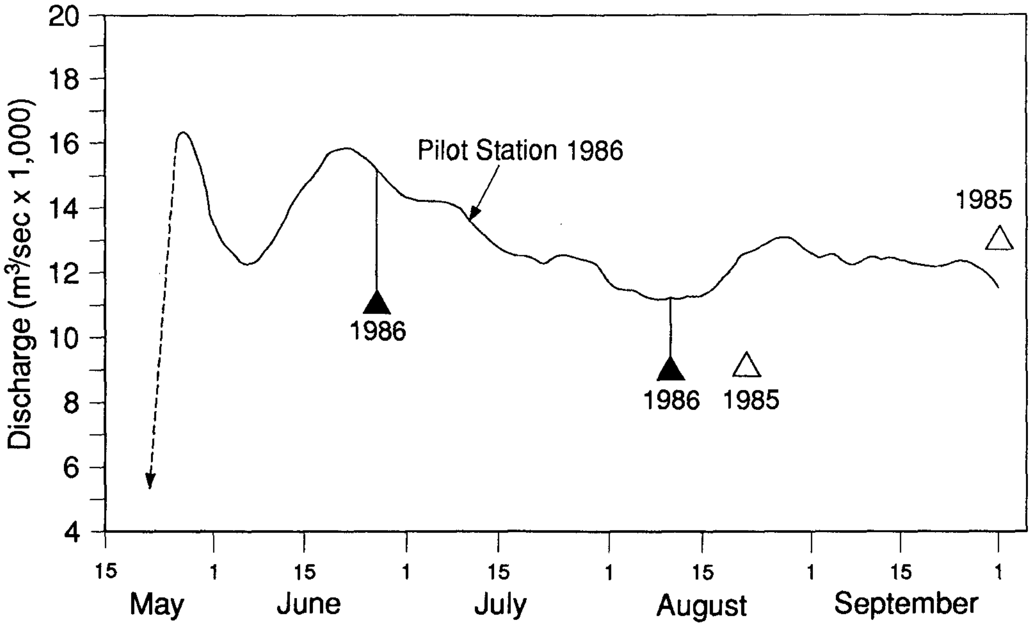

FIGURE 2.5—Daily Yukon River discharge estimates from Pilot Point, 1986, and Kobolunuk, 1985 and 1986. Triangles represent discharge estimates at Kobolunuk. (Adapted from McDowell et al. 1987.)

generated by the low atmospheric pressure associated with an intense storm, result in an overall transport of water into Norton Sound and elevated water levels against the open coast.

Hydrodynamic models developed to simulate storm surges in arctic regions (Kowalik 1984; Kowalik and Johnson 1985; Johnson and Kowalik 1986) have been applied to Norton Sound and have predicted extreme surge heights ranging from 1.6 to 2.0 m near the Yukon Delta. The most severe storm surges, resulting in the greatest property losses, have occurred in autumn. Wave flooding of coastal lowlands during June has reportedly had a serious impact on the nesting success of waterfowl (McDowell et al. 1987).

In order to study the frequency and severity of deltaic storm surge events, water level measurements and meteorological data were obtained at several coastal sites in 1986 (McDowell et al. 1987). Although there were no severe storms during the period of observation, there were two distinct events that produced storm surge effects in water-level variation. Winds from the northeast (10.0–12.7 m/s) lowered the sea level about 70 cm below mean sea level. When the winds reversed to the southwest, the water level rose 60 cm above mean sea level.

2.3.3 Tides

Tides in the Yukon Delta area are primarily influenced by the tidal dynamics of the eastern Bering Sea and Norton Sound. The tidal wave propagates counterclockwise from the western portion of Norton Sound (where water depths are 10–20 m), across the shallow flats of the delta platform (depths of 0.5–3 m), and impinges on the shoreline and into the river distributaries. Because the tide propagates with the phase velocity of a shallow water wave, its phase velocity is proportional to the square root of the depth. Since the shallow platform is traversed by narrow subaqueous channels originating at the mouths of river distributaries, the tidal wave may propagate more rapidly within the channels than across other shallow inshore areas.

The delta's complex topography is conducive to a high degree of spatial variability in the amplitude and phase of tides. Tidal energy dissipation due to friction is also accentuated over the very shallow areas; this frictional effect reduces tidal amplitudes near shore and decreases the phase velocity of the tide wave. In addition, within the major distributaries, the intense river flow opposes tidal propagation, reducing the phase velocity of the tide wave. Tidal propagation within Kwikluak, Kawanak, and Apoon passes is also affected by the numerous islands positioned near the river's mouths and the complex bottom topography of distributary channels.

Circulation of coastal waters near the Yukon Delta is consistent with the counterclockwise tidal rotation of the eastern Bering Sea. The south to north current direction is demonstrated in plots of the principal diurnal (K_1) and semidiurnal (M_2) tidal constituents

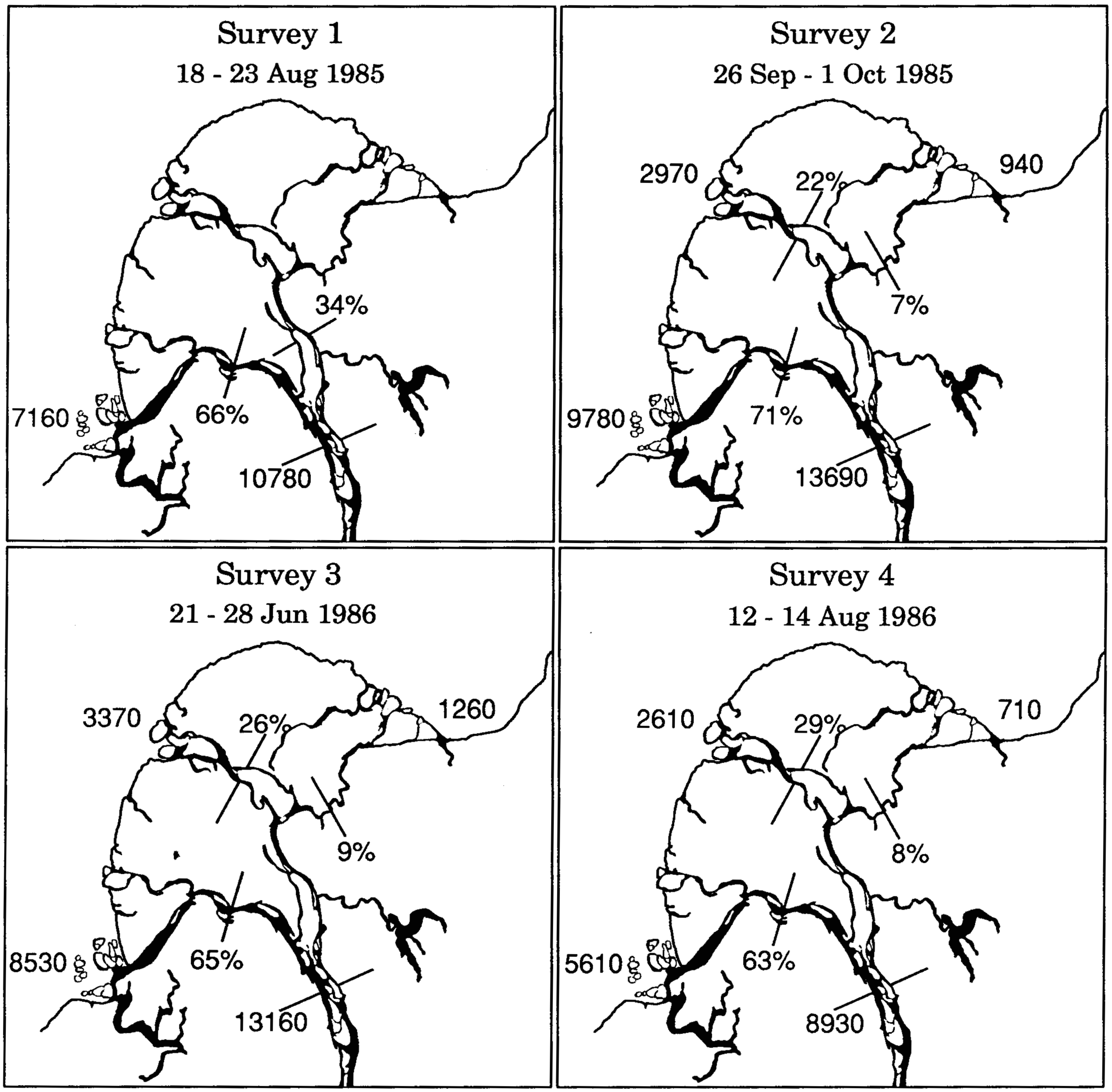

FIGURE 2.6—Distribution (percentage) of Yukon River discharge (in cubic meters per second) among the three major delta distributaries. (Adapted from McDowell et al. 1987.)

measured in 1986 (Figs. 2.7 and 2.8, respectively). The M_2 and K_1 tidal amplitudes at South Mouth were only 30% of their corresponding tidal amplitudes 27.5 km offshore (Station C–3). This 70% reduction in tidal amplitude illustrates an important concept; it indicates how the shallow topography surrounding the delta acts to dissipate tidal energy. Tidal amplitudes upstream of the distributary mouths are reduced even more.

In general, the phases of both tidal constituents increase rapidly with distance upriver from the coast (Figs. 2.7 and 2.8). River discharge within the distributaries contributes to the reduction of the phase velocity of the tidal wave. The few water-level measurements that are available from within the distributaries show a rapid upstream decay in tidal amplitudes (McDowell et al. 1987).

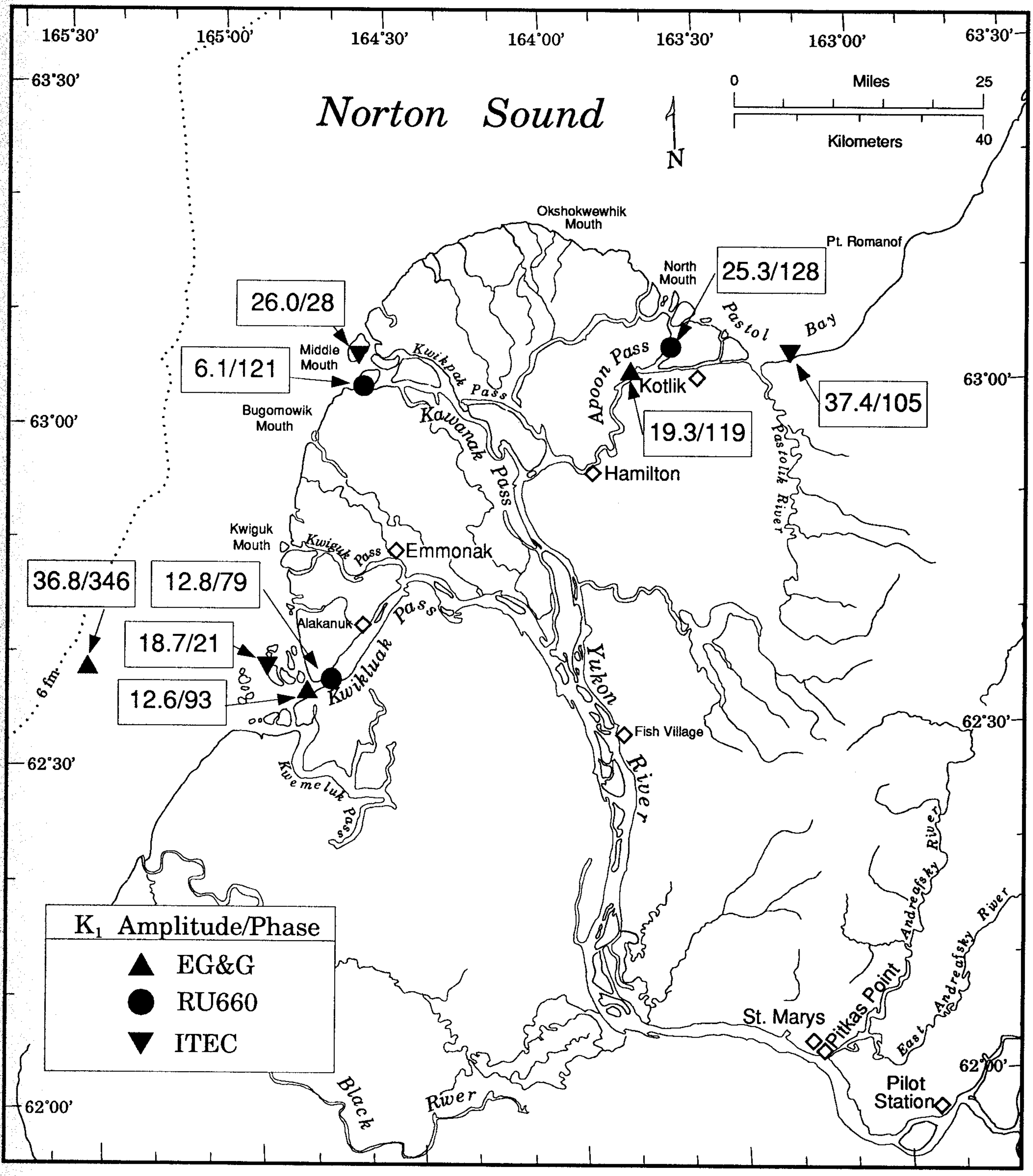

FIGURE 2.7—Spatial distribution of the amplitude (cm) and phase (degrees, referred to Greenwich) of the K_1 tidal constituent at measurement sites around the Yukon Delta. (Adapted from McDowell et al. 1987.)

In addition to a high degree of spatial variability in the amplitude and phase of tides, there is also significant spatial variability in the diurnal/semidiurnal tidal amplitude ratio along the delta coastline. This tidal amplitude ratio, defined as $F = (K_1 + O_1)/(M_2 + N_2)$ where O_1 and N_2 are dominant tidal components (principal lunar diurnal and larger lunar elliptic semidiurnal, respectively). The rationale for the description of F was

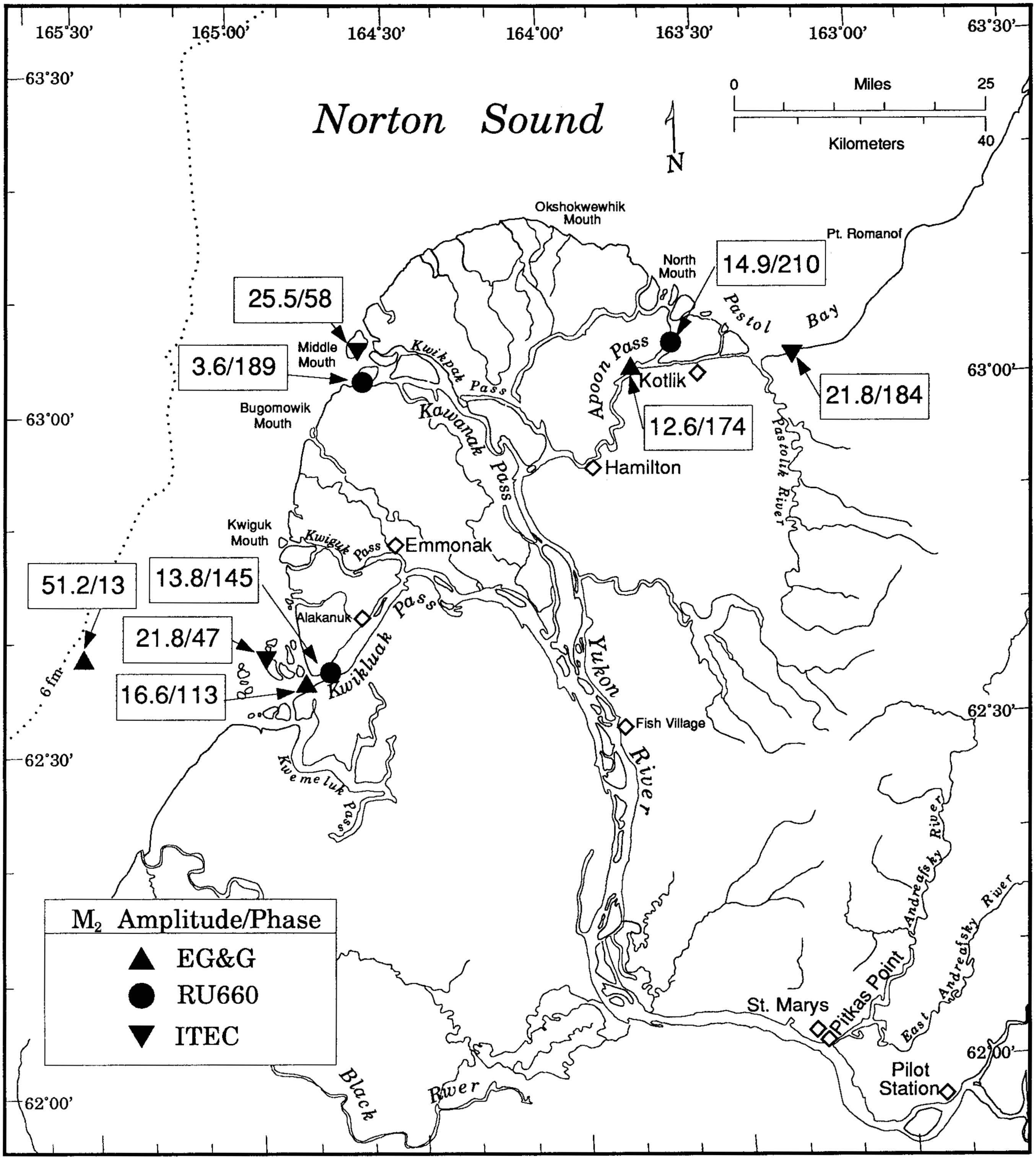

FIGURE 2.8—Spatial distribution of the amplitude (cm) and phase (degrees, referred to Greenwich) of the M_2 tidal constituent at measurement sites around the Yukon Delta. (Adapted from McDowell et al. 1987.)

introduced by Pearson et al. (1981) to characterize the tides in the eastern Bering Sea. Ratios ranging from 0.5 to 1.5 indicate predominantly semidiurnal tides, while ratios ranging from 1.5 to 3.0 indicate predominantly diurnal tides. The values of F for nine Yukon tide stations shown in Figure 2.9, and presented in Table 2.3, indicate a mixed, predominantly semidiurnal tide near the South Mouth and Middle Mouth. In

TABLE 2.3—Diurnal/semidiurnal tidal amplitude ratios (F)* from sites around the Yukon Delta (McDowell et al. 1987).

Station location	F	Measured by—
Offshore South Mouth	0.94	EG&G, 1985 and 1986
South Mouth	0.73	ITEC, 1982
	0.88	EG&G, 1985 and 1986
	1.18	OCSEAP RU 660, 1985
Middle Mouth	1.35	ITEC, 1982
	2.28	OCSEAP RU 660, 1985
North Mouth	2.32	ITEC, 1982
	2.22	OCSEAP RU 660, 1985
	2.15	EG&G, 1985 and 1986

*$F = (K_1 + O_1)/(M_2 + N_2)$.

contrast, all tide records from the North Mouth indicate a predominantly diurnal tide, with amplitude ratios greater than 2.

2.3.4 Salt-Wedge Intrusion

During periods of onshore storm-driven currents, waves and estuarine-type circulation mechanisms may result in intrusion of sea water into the distributaries (Zimmerman 1982). However, such intrusions apparently do not occur when strong summer discharges dominate the flow and water properties of nearshore areas surrounding the delta. In fact, McDowell et al. (1987) suggested that saline water from the Bering Sea was unable to penetrate the distributary mouths of the Yukon River during the summers of 1985 and 1986. Hydraulic calculations for late fall and early winter, when the river discharge beneath the shorefast ice cover is typically 1,000–2,000 m^3/s, suggest that salt-water intrusions could occur and affect distances tens of kilometers upstream. Seawater was observed 35 km from the river mouth in the Black River in December 1984 (Martin et al. 1986).

2.4 BATHYMETRY

Extensive bathymetric surveys of the lower Yukon River were conducted as part of the OCSEAP physical processes study (McDowell et al. 1987). Bathymetric data were collected from 60 river transects, spaced 3.2 km apart, extending downstream from Pitkas Point to the coast. These surveys revealed a complex system of erosional channels with maximum depths of 8–30 m. The deepest channels were located in areas where the river was constricted or adjacent to the bank at large meanders.

Even though a high degree of topographic variability was observed among the many channels of the Yukon River, it is still possible to characterize river segments by their bathymetric profile. Schematic diagrams of five channel profiles are shown in Figure 2.10. In each characterization water depth and transect length are secondary factors in the profile description. River sections fitting Profile 1 tend to have two channels separated by a middle shoal. The channels can have similar depths, but in most cases one channel is considerably deeper than the other. Profile 2 river sections also have two channels but are separated by an island or exposed bar. Profiles 3 and 4 are characterized by a single, deep channel adjacent to one bank and differ only by the relative width of the deep channel. Profile 5 represents river areas where a broad, relatively flat channel extends across their entire width.

This profiling system has been applied to data obtained from 46 transects located on the Yukon River between Pitkas Point and the South Mouth (McDowell et al. 1987). The number of transects of each characteristic profile type is summarized in Table 2.4. Eighteen transects (39%) fit Profile 1, having two distinct channels with a middle shoal. Another eight had two channels, but were separated by an island or bar. Thus, more than half of all the river transects studied had two channels. Profile 5 waters were also frequently encountered.

2.5 SEDIMENTOLOGY

The fan-shaped Yukon Delta is an actively prograding delta with growth largely attributed to the deposition of river-borne sediments during periods of heavy runoff (Dupré and Hopkins 1976; Dupré and Thompson 1979; Nelson and Nio 1982). Analyses of the suspended sediment samples and current meter data obtained in 1986 indicate a northward advection of fines into the Bering Sea in summer (McDowell et al. 1987). This supports an earlier contention that the delta front is migrating to the north in the direction of the dominant summer transport (Nelson and Creager 1977; Dupré and Thompson 1979).

2.5.1 Bottom Sediments

McDowell et al. (1987) obtained 22 bottom sediment samples from the Yukon Delta during 1985 and 1986. Analysis of these samples indicated that (1) there are no significant differences in the general grain size composition within the major river channels and delta platform, and (2) the grain size composition of river channel and delta platform sediments differed from that of the delta front and from the less-active side

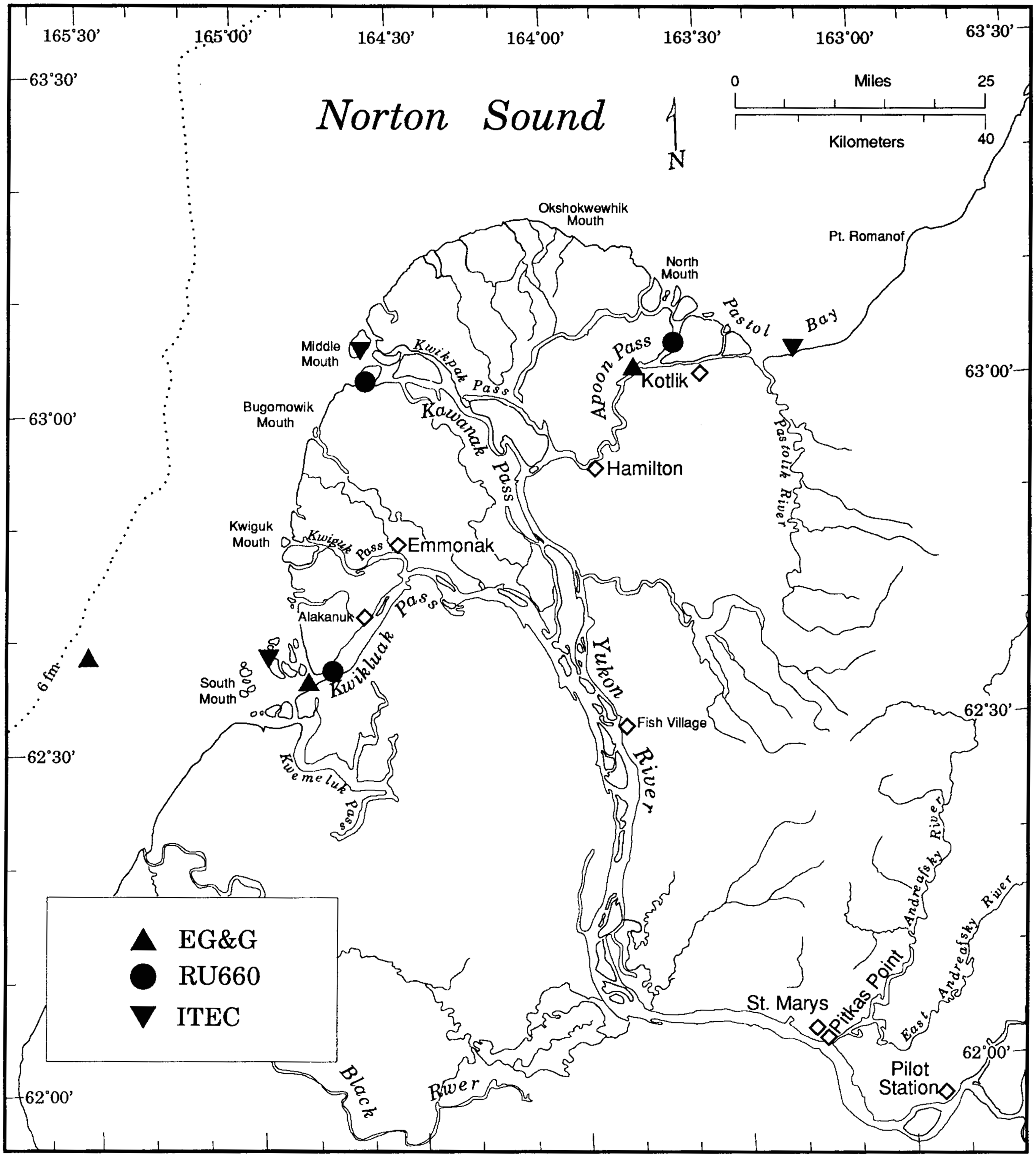

FIGURE 2.9—Locations of nine water-level records used in the analysis of tidal characteristics on the Yukon Delta. (Adapted from McDowell et al. 1987.)

channels and sloughs (McDowell et al. 1987). River channel samples taken at 13-km intervals between Pitkas Point and the South Mouth of the Yukon River showed bottom sediments to be generally 90% sand. Nearshore samples taken along a transect extending from South Mouth to the delta front tended to be of the same sediment composition as found in the major river channels, shifting to 60–70% silt, 20–30% sand,

and 5–10% clay offshore. Sediments in less active channels and midriver bars exhibited higher percentages of silt and clay than similar samples obtained in more active channels of the river.

The organic carbon content of bottom sediments from the river and the river mouth ranged from 0.1 to 1.9%. The sediments having the greatest organic carbon content tended to be associated with higher silt fractions.

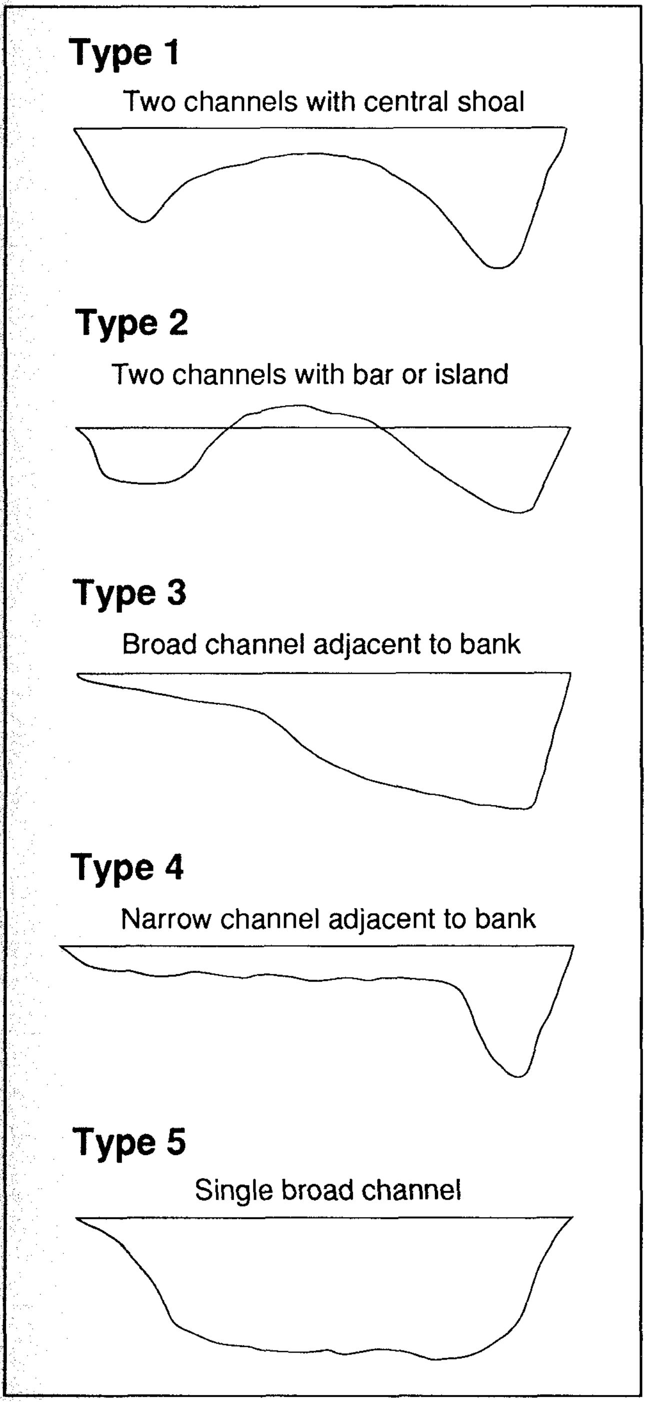

FIGURE 2.10—Typical bathymetric profile types in the lower Yukon River. (Adapted from McDowell et al. 1987.)

TABLE 2.4—Summary of bathymetric profile types in the Yukon Delta (McDowell et al. 1987).

Profile type	Number of transects Yukon River and Kwikluak Pass	Kwikpak Pass
1	18	6
2	8	1
3	7	3
4	2	0
5	11	4
Total transects	46	14

The clay component (and its bedrock sources) in sediment samples collected in large rivers has been used to examine sediment dispersal patterns in the Bering Sea relative the river of origin (Naidu and Mowatt 1983). McDowell et al. (1987) found that clay taken from Yukon River and delta front sediments was similar in composition. Percentages of smectite, illite, kaolinite, and chlorite were similar at all stations located around the delta (Fig. 2.11). The relatively high values of chlorite observed in the sediments are characteristic of the Yukon River. This river is thought to be the greatest contributor of kaolinite clays to the Bering Sea. These characteristics have been useful in identifying Yukon River sediments in Norton Sound and the southern Chukchi Sea.

2.5.2 Suspended Sediments

Notable differences in concentration levels of suspended sediments were observed at surface and bottom portions of the water column of the delta front. At each of three offshore stations, higher concentrations were noted near the bottom. Oceanographic data (CTD) collected in conjunction with the suspended sediments indicated a highly stratified water column characterized by Bering Sea water overlain with brackish river water (McDowell et al. 1987).

2.5.3 River Transport of Suspended Sediment

Dupré and Thompson (1979) estimated a mean annual suspended sediment concentration of 475 mg/liter for the Yukon River, associated with a mean annual discharge of 185 km^3 of water into the Bering Sea. This reflects an estimated suspended transport of 88 x 10^6 t/yr. McDowell et al. (1987) reported similar levels of sediment transport for 1985 and 1986. Suspended sediment in the river averaged 455 mg/liter in July 1985, 166 mg/liter in September 1985, 185 mg/liter in June 1986, and 234 mg/liter in August 1986.

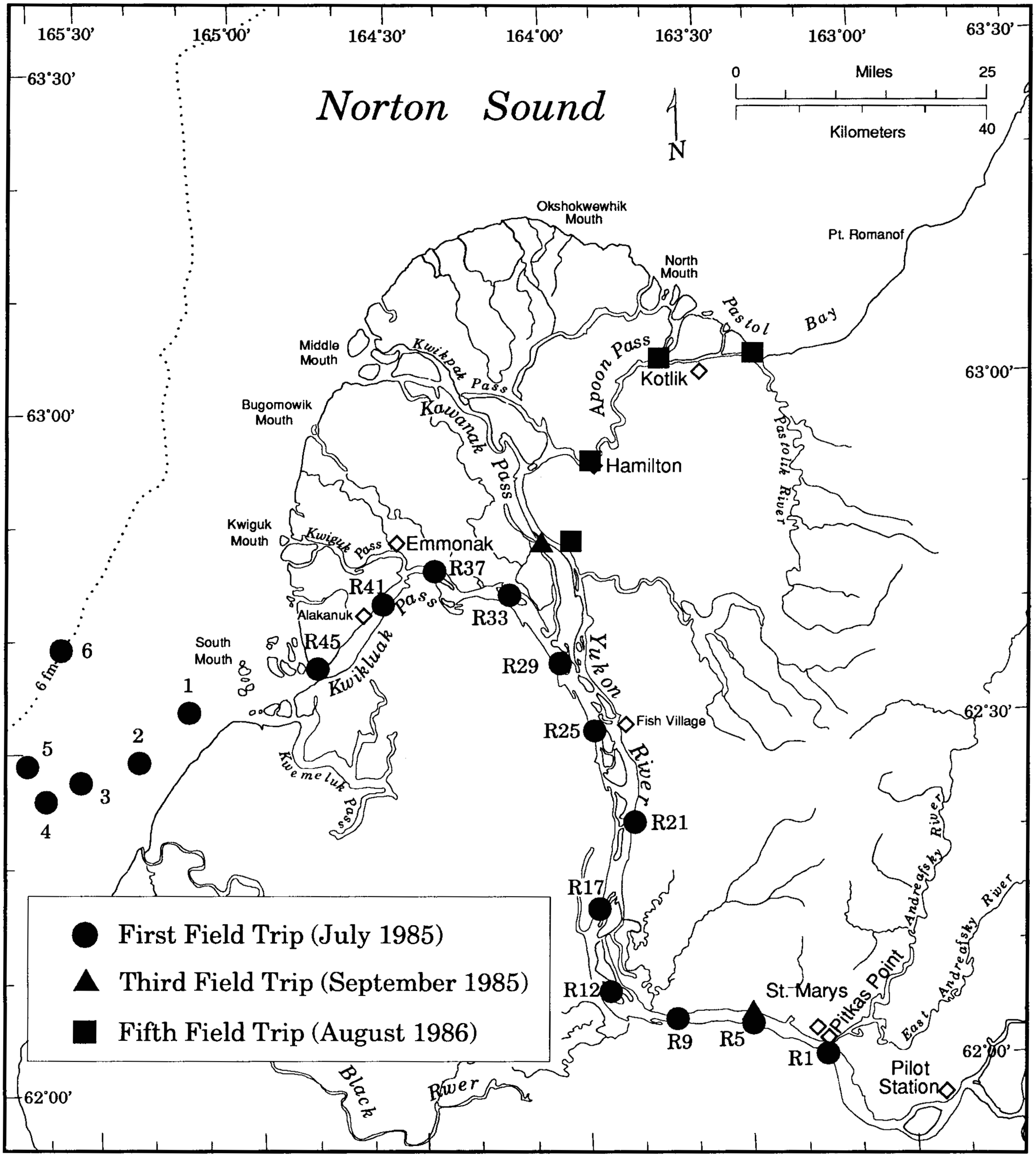

FIGURE 2.11—Sediment sampling locations, 1985 and 1986. (Adapted from McDowell et al. 1987.)

Using estimates of river discharge velocities, McDowell et al. (1987) calculated suspended sediment loads of 196 × 10^3 t/d in September 1985, 209 × 10^3 t/d in June 1986, and 181 × 10^3 t/d in August 1986. (Estimates of sediment transport for July 1985 were not possible because river discharge information was not available.) These estimates are roughly 50% lower than those reported by Dupré and Thompson (1979), reflecting a lighter suspended sediment load in the latter years and interannual variability.

2.6 COASTAL CIRCULATION

Circulation in the northern Bering Sea, and near the Yukon Delta, is dominated by a northward mean flow paralleling the local bathymetry (Fig. 2.12). The northerly mean flow is not wind-driven, but is a direct result of differences in density (Coachman and Aagaard 1981; Stigebrandt 1984). Seasonal fluctuations are superimposed on the mean flow. The sea surface slope can be enhanced or eliminated by atmospheric forcing, as evidenced by frequent reversals, from northerly to southerly, of currents in the Bering Strait (Aagaard et al. 1985).

No long-term measurements of coastal currents near the Yukon Delta are available. Current meter data are, however, available from Shpanberg Strait. Oceanographic data collected intermittently between 1976 and 1978 from instrument moorings located 64 and 97 km west of the Yukon Delta indicate that during winter the sea ice modifies regional circulation by reducing mean current speeds by almost 30%, despite increased wind speeds (Salo et al. 1983). This is not unexpected, as similar patterns of diminished tidal currents and heights have been observed in other arctic environments. In Shpanberg Strait, 30–35% of the total kinetic energy is associated with tides.

A detailed analysis of the energy spectrum of winter currents in Shpanberg Strait revealed meteorologically forced 5-day and 10-day peaks (Salo et al. 1983). These peaks were correlated with current reversals (southerly flows) in the Shpanberg Strait; 15 to 20 such reversals occurred during the oceanographic survey period. The magnitude and the direction of the vector mean current in the strait (4–7 cm/s, 354–035° T) is primarily a function of the number and strength of these flow reversals.

Oceanographic studies conducted in Norton Sound by OCSEAP during the summers of 1976, 1977, and 1978 indicate that Yukon River water is occasionally transported into eastern Norton Sound; it has reportedly been advected beyond Stuart Island well into inner Norton Bay (Muench et al. 1981). The presence of Yukon River sediments in eastern Norton Sound further substantiates such transport (Drake et al. 1980).

During the summers of 1985 and 1986, short-term (3–8 weeks) oceanographic data were obtained from two current meters moored within 25 km of the Yukon Delta. The current measurements indicated a mean northward drift of about 12 cm/s in the coastal waters near the South Mouth and Middle Mouth. In the summer of 1985, both moorings were apparently located in a frontal zone between warm, low salinity river water and cold, saline ocean water. Analysis of temperature and salinity data revealed that strong northward flow occurred when warm, low salinity river water was present, in contrast to periods of weak, predominantly tidal motion when cold, saline ocean water was present. These results suggest that the water mass boundary between Yukon River water and Bering Sea water is a dynamic boundary for current-generating processes.

The observed currents also provided evidence that the deltaic flow regime is related to meteorological events and that wind-driven currents on the west and north sides of the delta are different. Ekman dynamics prescribe that strong northerly winds, north of the delta, would result in primarily onshore currents with a small westward component. However, the same northerly winds along the western margin of the delta would result in strong alongshore currents with a small offshore component. In contrast, a strong southerly wind would result in onshore flow at South and Middle mouths, while the nearshore flow would be primarily offshore at North Mouth.

The component of the surface wind that runs parallel to the coastline may result in upwelling or downwelling depending on the direction of the wind. The prevailing winds in the Yukon-Kuskokwim Delta region are southerly, favoring convergence or downwelling along the western side of the Yukon Delta. In contrast, when the winds are northerly, upwelling occurs in the same region.

However, such a wind-driven mechanism of water mass dispersal may be limited by the currents and structural properties that exist off the Yukon Delta. This is especially true of frontal areas occurring between the river plume and saline Bering Sea water.

2.7 HYDROGRAPHY

The Yukon Delta is located in a region of extreme seasonal variability. The climatological data indicate that mean sea-surface temperatures during the open-water period range from a minimum of 0.5°C in May to a maximum of 11°C in July. Minimum temperatures in summer are about 5°C, whereas during periods of ice cover the surface temperatures can approach −1.8°C.

The results of hydrographic surveys conducted in the vicinity of the Yukon Delta in Norton Sound during the summers of 1976 and 1977 and the winter of 1978 provide a detailed picture of the hydrography in the region (Muench et al. 1981). During summer, the waters of Norton Sound are characterized by two layers separated by a pycnocline. The warm, dilute upper layer is maintained by buoyancy inputs including solar

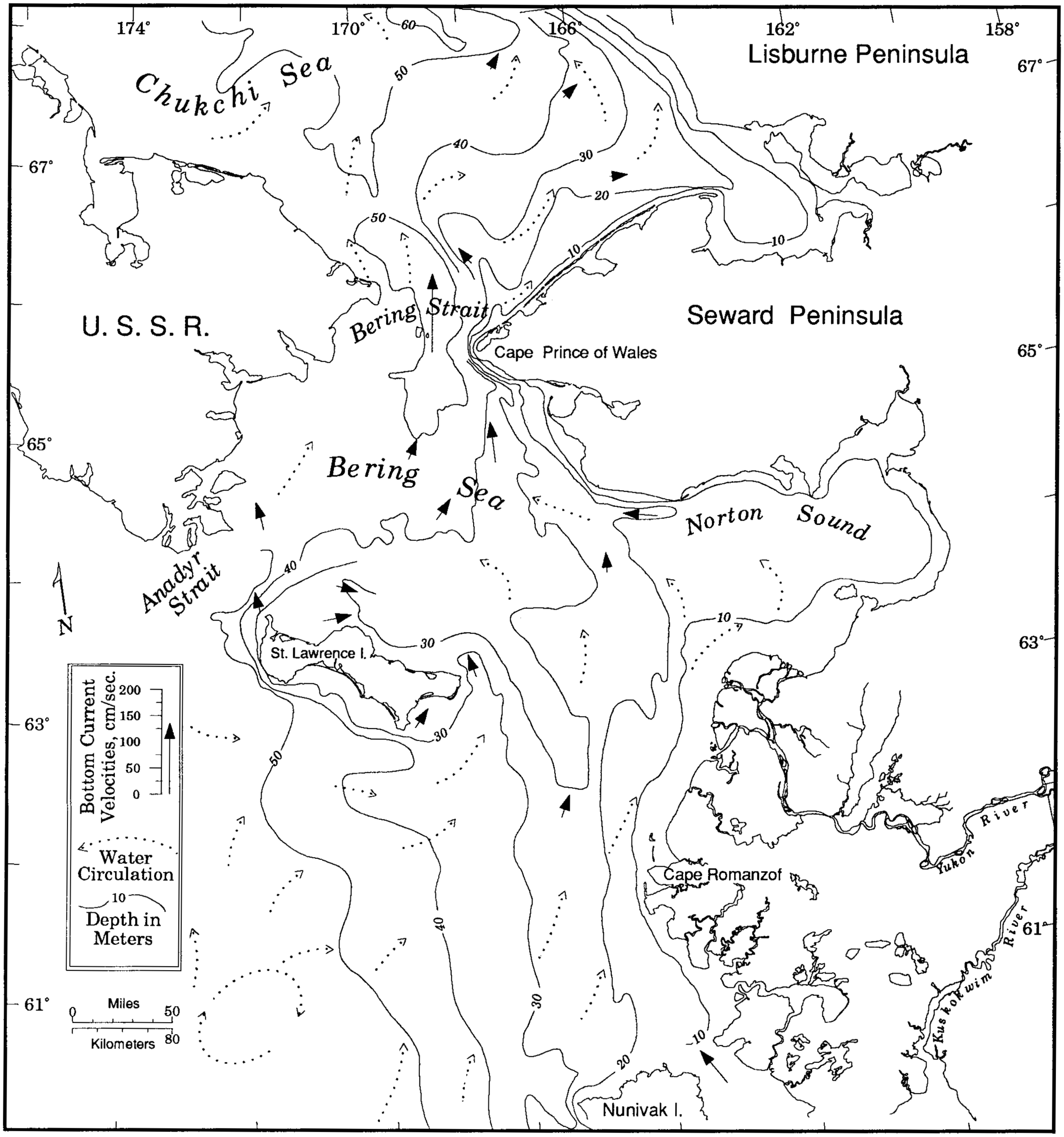

FIGURE 2.12—Offshore water circulation and maximum bottom current velocities from measurements in the northern Bering Sea. (Adapted from Nelson et al. 1981.)

heating, freshening by the Yukon River, and ice-melt. The spatial and temporal variability of the surface layer is high. During summer, surface temperatures and salinities in Norton Sound ranged from 6 to 16°C and 16 to 31 ppt, respectively (Muench et al. 1981). Near-bottom water properties exhibit less variability because they are isolated by the pycnocline from river effluent. Bottom temperatures ranged from 1 to 9°C and salinities from 26 to 34 ppt during summer throughout Norton Sound (Muench et al. 1981).

During winter, the waters in Norton Sound are completely mixed. This is due to vertical convection

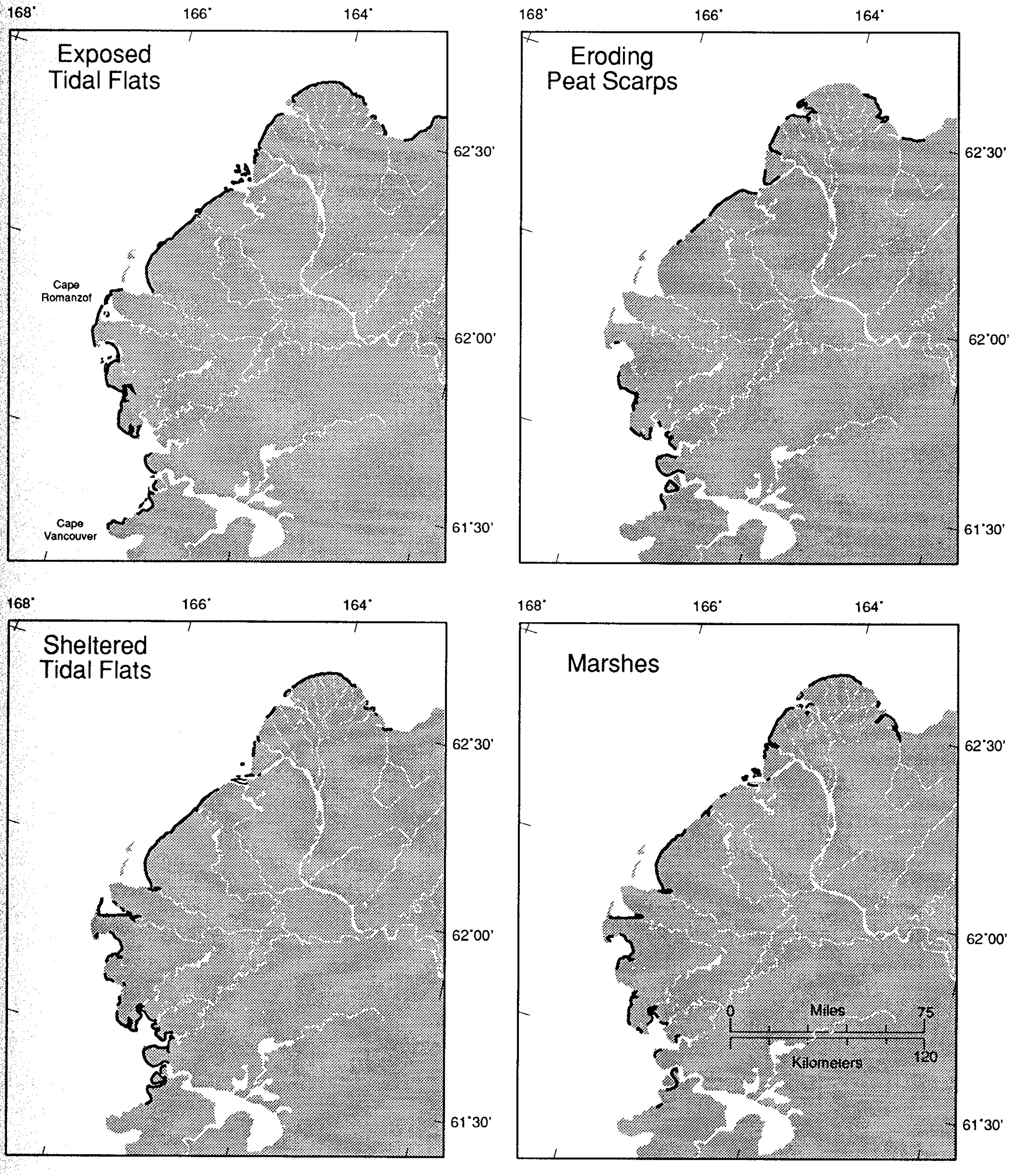

FIGURE 2.13—Distribution of exposed tidal flats, eroding peat scarps, sheltered tidal flats, and marshes in the Yukon Delta. (Adapted from Gundlach et al. 1981.)

processes resulting from cooling, wind-induced mixing, decreased river discharge, and ice formation. Regional waters are nearly isothermal approaching the freezing point (−1.6 °C in 1978; Muench et al. 1981). Salinities also exhibit much less vertical and horizontal variability than during the summer months; salinities ranged from 30.0 to 31.6 ppt throughout February 1978 (Muench et al. 1981).

Hydrographic conditions 20–30 km off the Yukon Delta are similar to those of Norton Sound. Oceanographic measurements taken 24 km west of the delta by McDowell et al. (1987) indicated stratified conditions in summer with a freshwater layer (salinity about 1 ppt) over a saline layer (about 25 ppt), or completely mixed isothermal and isohaline conditions. Sea waters were found only at stations located 15–20 km off the western margin of the delta at the edge of the delta platform, or farther offshore over the steeply sloping face of the delta front.

2.8 ENVIRONMENTAL SENSITIVITY MAPPING

The sensitivity of Norton Sound and the Yukon–Kuskokwim coastal habitats to spilled oil has been evaluated in a series of regional maps (Gundlach et al. 1981). These maps portray shoreline sensitivity as a function of geomorphic, biological, and socioeconomic attributes. Beaches are ranked on a scale of 1–10 using an environmental sensitivity index (ESI) developed from those attributes, with the higher values being associated with coastal areas most sensitive to spilled oil. This classification system is widely accepted and commonly used throughout the United States.

The ESI maps have many practical applications. In Norton Sound, they have been used extensively by the Minerals Management Service in the analysis of risk to resources from oil spills as part of their environmental impact statements for this region. The ESIs have also proved indispensable in oil spill contingency planning and response. In this example, the maps provide a quick coastal reference to aid in decisions relating to protection of resources and cleanup strategies in the event of an oil spill. The coastal sensitivity mapping has also included, as part of the analysis, spill response recommendations for regional shoreline types. Beach types likely to be encountered include:

1. Exposed rocky headlands
2. Wave-cut platforms
3. Fine-grained sand beaches
4. Coarse-grained sand beaches
5. Exposed tidal flats
6. Exposed, mixed sand and gravel beaches
7. Gravel beaches

7a. Sheltered, mixed sand and gravel beaches

7b. Basalt-boulder beaches

8. Sheltered rocky shores

8a. Eroding peat scarps

9. Sheltered tidal flats
10. Marshes

Within Norton Sound, the Yukon Delta was ranked the most sensitive of all coastlines studied. It is an area of extensive marshes and tidal flats supporting millions of migratory shorebirds and waterfowl. Nearshore waters are heavily used during the open water season by populations of anadromous fish. The Yukon Delta shoreline is composed of overlapping exposed and sheltered tidal flats and eroding peat scarps and marshes (Fig. 2.13). In addition to the long-term persistence of oil within the sheltered tidal beaches, the continual offshore transport of sediments from the Yukon River provides a potential mechanism for transporting oil contaminants to estuarine and marine deltaic and Norton Sound habitats.

Chapter 3

The Biological Environment

3.1 PRIMARY PRODUCTIVITY AND PLANT ECOLOGY

The Yukon Delta is characterized by relatively flat topography comprising a low, flat alluvial deposit at the river mouth. The delta is bordered to the north and east by a volcanic mountain range. The coastal vegetation is a complex of plant forms generally associated with wet or moist tundra. Delta soils tend to be deeply embedded silts, sands, and gravels.

Few synecological studies have been conducted in western Alaska. Regional investigations have consisted of Landsat and range mapping of productive goose habitat. Otherwise, much of what has been reported concerning deltaic plant communities has come from casual observations in various wildlife investigations (Tande and Jennings 1986). Although botanical research has been limited, surveys have resulted in the identification of at least 282 vascular plants in the Yukon–Kuskokwim region. In general, inland areas appear to be dominated by tussock sedges, scattered willows, and dwarf birches. The coastal vegetation changes to extensive meadows of grasses and sedges (Viereck and Little 1972).

3.1.1 Geomorphology and Plant Associations

Complex vegetation patterns are common in arctic areas where permafrost is present (Tande and Jennings 1986). On the Yukon–Kuskokwim Delta small changes in elevation, with associated changes in soil moisture, are reflected in subtle differences in vegetation over short distances. The U.S. Fish and Wildlife Service (USFWS) has developed a vegetation classification and mapping scheme that has been used for more than 10 years on Alaska's North Slope. Their method, which involves Landsat imagery and ground truthing, has been used in tundra research near Hazen Bay (Tande and Jennings 1986). Hazen Bay is part of the Yukon River National Wildlife Refuge and is located slightly south of the Yukon Delta. This particular bay was chosen for study because of its importance to nesting populations of Pacific white-fronted and cackling Canada geese, black brant, and emperor geese. The work has resulted in an automated Geographic Information System (GIS) that describes vegetative cover as units expressed as a function of moisture, plant community and dominant taxa. Information on local geomorphology, including landscape descriptors, percentage of open water, surficial geology, and miscellaneous site information, is included in this analysis. Data for the Yukon Delta are scarce; however, given the proximity and environmental similarity to Hazen Bay, it is likely that the dominant plant associations are similar. The major similarities in coastal geology and transport processes are depicted in Figure 3.1.

The sedimentation of arctic, ice-dominated deltas is thought to be morphologically different from that of wave-, river-, or tide-dominated deltas (Dupré 1980). Although the difference is largely due to the prograding portion of the delta, patterns in plant community dominance are ultimately related to surficial and bedrock deposits, to distinct changes in their elevation and moisture, and to effects of frost action. Tande and Jennings (1986) found that the surficial deposits of the Yukon–Kuskokwim Delta are not easily mapped or classified on a lithological basis. Mapping was possible if the evolutionary depositional histories of broad sections of the deltaic environment were considered. The main features and geologic processes of the Yukon–Kuskokwim Delta (Tande and Jennings 1986; Fig. 3.1) were also described in part by Dupré (1978) in his development of a geomorphological model of the Yukon Delta (see Fig. 2.1). Synecological information from Tande and Jennings (1986) has been incorporated in the following description of Yukon Delta geomorphology and dominant plant associations.

Chenier Plain.—A chenier plain is a narrow low coastal beach or marsh that forms as the result of a variable sediment supply (Snead 1982). The Yukon River chenier plain is located south of the Kwikluak Pass. This beach has formed with variable sediment input from the Yukon River. Beach ridges are characterized by silt and sandy silt fine materials. The landscape is continuously interrupted by thaw lakes. Grasses and forbs dominate the coastal flora.

Fluvial Plain.—The surficial deposits are fluvial, including old coastal plain and deltaic deposits laid

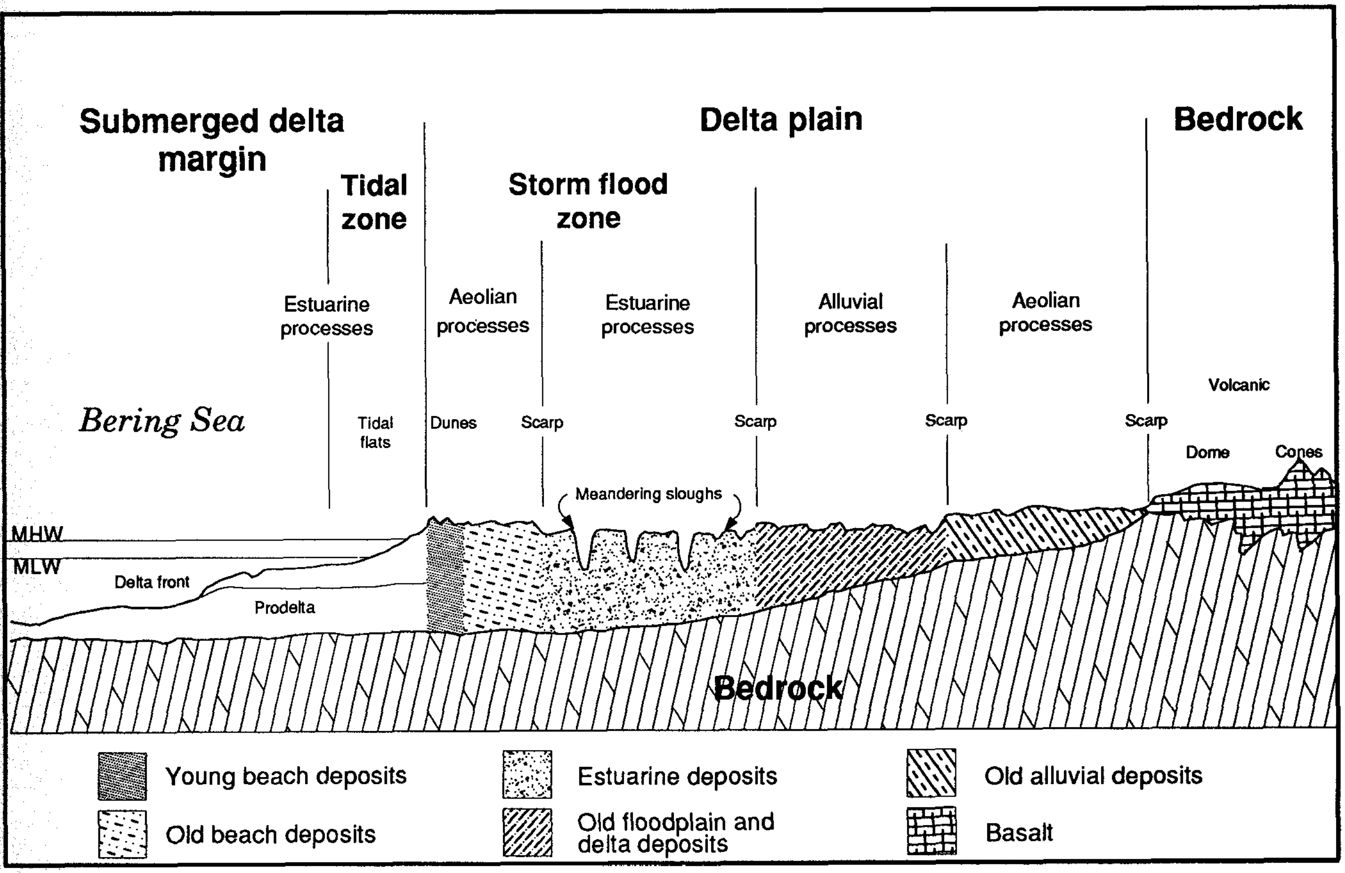

FIGURE 3.1—Schematic diagram of the features of the Yukon–Kuskokwim Delta, indicating the principal geological processes operating in each region. (Adapted from Tande and Jennings 1986.)

down by the ancestral Yukon and Kuskokwim rivers. These deposits have been reworked by ocean currents and wind near the coast, forming extensive sandbars. The surficial deposits are composed of silt and fine sand with admixed woody material. Most are permanently frozen to depths of at least 60–90 m and surface thawing has produced the delta's ubiquitous thaw lakes. The tundra vegetation is dominated by sedges, mosses, lichens, and low shrubs.

Tidal Flats and Distributary Mouth Bars.—The shallowness of Norton Sound, combined with the marked seasonality of marine and fluvial processes, has resulted in a complex pattern of sediment resuspension and reworking (Dupré 1980). Unlike the macrotidal influence of the Bering Sea on the Kuskokwim Delta, the microtidally influenced Yukon Delta is fringed by tidal flats and distributary mouth bars. Tidal flats are typically 100–1,000 m wide and consist of poorly sorted sandy silts in low wave energy portions of the northern side of the delta and moderately sorted silty sands on the western side of the delta. Detrital peat is abundant in the upper portions of the tidal flat. Distributary mouth bars form at the mouths of the major river distributaries. They are characterized by moderately to well-sorted sand in areas of high energy and silty sand in areas of low energy.

Barren mudflats can occur on the coast, on riverbanks, along tidal sloughs, and in drained lake and pond basins. In other areas the dominant plant forms include nearly pure stands of grasses and sedges or mixed communities of grasses, sedges, and willows. In some coastal areas where mudflats are flooded daily, i.e., open mudflats of drained lakes and river bars near the mouths of major rivers, pure zones of *Puccinellia* occur seaward of *Carex*. Sandbars are usually barren.

South of the South Mouth of the Yukon River, scattered peat blocks and drift are present. The vegetation along eroding shorelines in this area is dominated by the sedge *Carex ramenskii*.

Delta Plain.—The delta plain consists of a complex assemblage of active and abandoned distributary channels and channel bars, natural levees, interdistributary marshes, and lakes. There is evidence of permafrost but it is discontinuous in distribution. Flooding is a major hazard on much of the delta plain, as are erosion and sedimentation associated with the meandering active distributaries. Sediments deposited in the channels and channel bars consist of relatively well-sorted sands and silts.

Interdistributary areas in the older, inactive portions of the delta plain consist of poorly sorted peaty silt and mud (Dupré 1979). Along the coast these marshes consist of salt-tolerant grasses and sedges, typically forming over actively prograding tidal deposits. Low washover ridges prevent inundation and shoreline erosion except during periods of severe storm surge. Farther inland the cover becomes thicker and is characterized by sedge tussocks, low shrubs, forbs, mosses, and lichens. Willows, alders, cottonwoods, grasses, sedges, horsetails, and other tundra plants are common on beds of naturally drained thaw lakes and narrow drainageways connecting lakes and ponds. Blueberries and low bush cranberries are common. Willows, sedges, mosses, and low shrubs are found along low terraces near major streams. Willows, alders, and grasses are prominent plant forms along natural levees.

A narrow band of forest occurs along the Yukon River, extending almost to the Bering Sea (Nunam Kitlutsisti 1982). Few species are present, occurring in small stands interspersed with scrub growth or areas of muskeg or bog. Black spruce (*Picea mariana*), white spruce (*P. glauca*), birch (*Betula papyrifera*), and poplar (*Populus balsamifera*) are prominent species.

Prodelta.—A relatively small portion of the sediment entering Norton Sound from the Yukon River is deposited in prograding tidal flats and distributary mouths. Most is transported offshore. Wave-induced current reworking of sediments occurs some 20–30 km offshore in the vicinity of the delta front, resulting in fairly well-sorted sandy shoals in this region that appear to be migrating to the northeast.

3.1.2 Ecological Zones

Truett et al. (1984) described ecological zones (Fig. 3.2) along the lower Yukon River on the basis of similarities in physical qualities and patterns of animal use. Geobotanical information has been added to these characterizations in this report to suggest the likely plant communities typical of the various zones. The discussion of probable indicator species is qualified by the multitude of "microhabitat types" of the delta. Each is characterized by its own assemblage of dominant communities and plant forms. For example, the USFWS Hazen Bay research has resulted in the classification of 77 community types containing 31 dominant tundra growth forms (Tandé and Jennings 1986). Although dominant forms have been identified in a number of wetland types, no specific research has focused on the wetland component of the deltaic ecosystem. The plant communities likely to be typical of the Yukon Delta ecological zones are as follows:

(1) The ***highlands*** are inland areas not influenced by deltaic processes. The lower elevations of this zone represent a transitional moist environment between inland bedrock and surficial deposits. In spring this is the last area where snow melts. The plant community is similar to that found in many drainage channels, thaw lake shorelines, and basins found in the delta landscape. Low and tall shrubs are surrounded by grasses, sedges, and forbs. Species richness is high, and dominants include *Calamagrostis canadensis, Salix planifolia, Betula nana, Spiraea beauverdiana, Epilobium angustifolium, Petasites frigidus,* and *Dryopteris dilatata.* High beaver use is suspected in this transitional upland area.

In the drainage courses of hillside slopes, tall shrubs predominate. The diamondleaf willow (*Salix planifolia*) and green alder (*Alnus crispa*) are representative species. The remaining hillside is likely vegetated by a drier-site community type. This would include a complex of non-tussock sedge, dwarf shrub, and fruticose lichen covers. Representative species might include *Dryas integrifolia, Cladonia rangiferina, C. amaurocraea, C. arbuscula, C. unicialis, Alectoria ochrleuca, Cetraria cucullata, C. islandica, Cornicularia divergens,* and *Carex aquatilis.*

(2) The ***delta uplands*** are the highest delta environments above sea level. They are slightly elevated, wooded levees. The most common inland upland community type consists of a non-tussock sedge, dwarf shrub, and fruticose lichen plant assemblage. These peatlands are characterized by the low-growing sedge *Carex aquatilis* and dwarf-shrub hummocks on a moss mat. The most common mosses are the feather mosses *Dicranum* and *Sphagnum.* Lichens include moderate amounts of *Pelttigera* spp., *Stereocaulon* spp., *Nephroma arcticum,* and reindeer lichens. Along the coast, crowberry (*Empetrum nigrum*) is the dominant dwarf shrub; farther inland, dominance shifts to the tea-like tundra shrub *Ledum decumbens* and the dwarf arctic birch, *Betula nana.* Depressions and troughs, common throughout the delta uplands, are saturated with a mat of green or yellow-green *Sphagnum* species associated with moderate covers of the cotton grass *Eriophorum russeolum* in a wet sedge–moss secondary community.

Moist forb dwarf shrub–moss heaths cover young ice-heaved deltaic areas, or palsas. This community is often associated with the banks of large thaw lakes, channels, and old streams. Dominant species include butterbur (*Petasites frigidus*), cloudberry (*Rubus chamaemorus*), and tundra tea and dwarf birch shrubs.

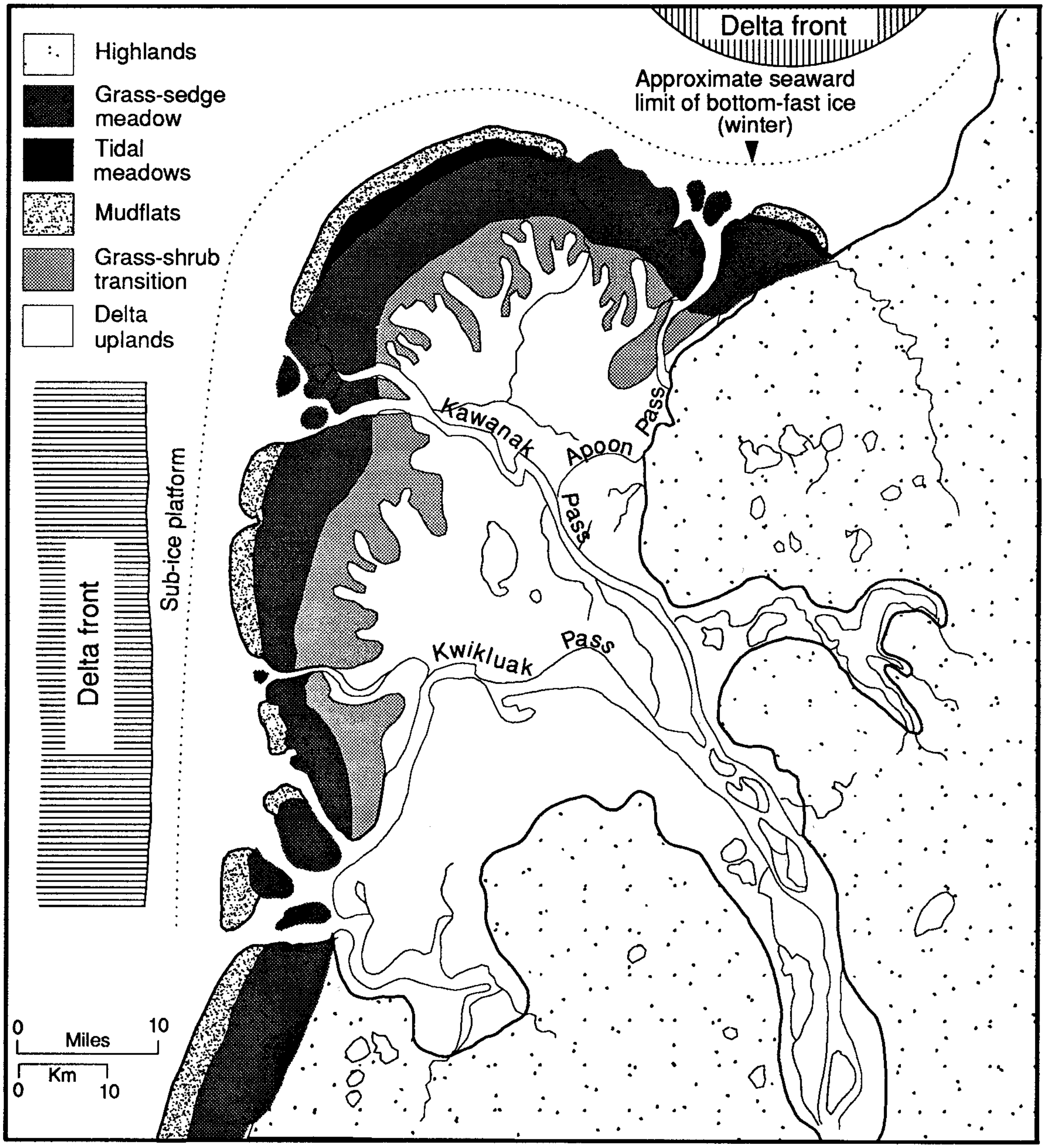

FIGURE 3.2—Ecological zones in the Yukon Delta. (Adapted from Truett et al. 1984.)

Blueberries (*Vaccinium uliginosum*) and lowbush cranberries (*V. vitis idaea*) are also found in this zone. This community is also found in elevated "islands" of the transition grass–shrub zone. These slightly elevated coastal areas appear to be favored fox denning sites.

Lakes and ponds are larger and fewer in the delta uplands. Lakes, ponds, and inside bends of riverbanks are surrounded by sedge meadows. Species dominance in these stands changes along the floodplain of the Yukon River. A sedge–cottongrass association of *Carex lyngbyaei–Eriophorum angustifolium* is common inland and upstream. Areas closer to the coast are dominated by nearly pure stands of the sedge *Carex ramenskii.* Common species associations might include freshwater forms such as horsetail (*Equisetum fluviatile*), sedge (*Carex rostrata*), buckbean (*Menyanthes trifoliata*), buttercup (*Ranunculus pallasii*), and wetland grass (*Hippuris vulgaris*).

(3) The ***grass–shrub transition*** occurs coastward of the delta uplands and is generally slightly lower and wetter. Many transitional sedge/grass–shrub vegetation complexes occur on the Yukon–Kuskokwim Delta. According to Truett et al. (1984) this zone is most commonly dominated by the willow *Salix ovalifolia* near the coast, changing to *S. fuscescens* inland. Dense growths of sedges, grasses, and dead plant material may

be intertwined with the *Salix.* Sedge (*Carex glareosa*), sweet-pea (*Lathyrus maritimus*), butterbur (*Petasites frigidus*), and crowberry (*Empetrum nigrum*) are commonly associated species, especially in the drier sites.

(4) The ***grass§sedge meadow*** transition zone is dominated by wetland grasses and sedges. This zone does not flood during normal high tides but is subject to inundation from moderate storm surges. Many ponds and temporary wetlands are present in early June but not thereafter.

The grass–sedge meadows are characterized by the graminoid–forb complex dominated by *Carex ramenskii* and the wetland grasses *Arctophila fulva* and *Hippuris tetraphylla.* This zone is an intermixing of coastal sedge meadows (nearly pure stands of *C. ramenskii* occurring inland of *H. tetraphylla, A. fulva,* and *C. lyngbyaei*) and wet, grass-forb meadows (dominated by *A. fulva* and *H. tetraphylla*) occurring in mudflat, riverine, and marshy habitats.

(5) ***Tidal meadows*** located below the grass–sedge meadows are dominated by the sedge *Carex ramenskii* in nearly pure stands. This zone is frequently flooded by high tides and occupies narrow tidal and abandoned stream channels. Associated species include grasses (*Hippuris tetraphylla* and *Dupontia fischeri*), bush cinquefoil (*Potentilla egedii*), and saltwort (*Salicornia* spp.)

(6) ***Coastal mudflats*** extend from the normally emergent coastal edge as far as 1 to 1.5 km offshore. These mudflats are frequently exposed at low tide but under water at other times. A broad, gentle rise parallels the coast at the outer margin of this zone, impounding a shallow basin of relatively clear water (5–12 cm deep) at low tide. During summer, clearwater zones support an abundant growth of pondweed (*Potamogeton filiformis*) in the coastal area between the Middle Mouth and North Mouth.

(7) The Yukon Delta has many ***minor distributary channels and sloughs*** that are subject to flushing during the peak flows of spring. After peak discharges of the Yukon River in June most of this zone is not fed by river water but is open to the sea or other sloughs.

(8) ***Major distributary channels*** include the major distributaries or passes of the Yukon River before entering the Bering Sea: the south Kwikluak Pass, the middle Kwikpak Pass, and the north Apoon Pass. These distributaries flow year round, are usually 0.5–3 km wide, and are relatively deep, up to 10 m or greater depths.

(9) The ***delta platform*** extends from the outer edge of the coastal mudflats to the delta front. It is characterized by a very gentle slope such that its seaward boundary is located 20–30 km offshore in waters approximately 3 m deep. The outer edge often approximates the seaward extent of landfast ice during the winter months. This ice, often as thick as 1 m, can be bottomfast some distance offshore. This habitat is criss-crossed by subsea channels of the major river distributaries.

The nearshore zones of the deltaic habitats (Zones 7–9) are characterized by turbid, turbulent distributary and coastal waters (Martin et al. 1986), which may result in depressed phytoplankton productivity. The Yukon Delta's extensive emergent marsh is probably the major source of export of detrital organic matter into the nearshore environment.

(10) The slope of the ***delta front*** is much steeper, increasing in depth from 3 to 14 m over a distance of 5 km. The delta front borders an area of mixing of Yukon River and Alaska Coastal Water.

(11) The ***marine environment*** comprises the continental shelf waters offshore of the delta front. ISHTAR researchers have estimated the average nitrate content of the Yukon River at 12 mg-at NO_3/m^3 or a riverine loading of 7.4×10^5 mg-at NO_3/s, about 3% of the Bering and Chukchi sea shelf-break input (McRoy et al. 1985). Time series chlorophyll data on annual productivity from one 1983 station in arctic coastal waters near Cape Lisburne, Chukchi Sea, indicate one seasonal plankton bloom. In more southern coastal waters where ice breakup is earlier, two blooms may occur; one with winter-supplied nutrients, and another with Yukon River inputs. There is, however, presently no evidence to support this (McRoy et al. 1985). The relatively small riverine input of nitrogen apparently leads to five-fold less primary production in Alaska Coastal Water, with an annual primary production of diatoms, flagellates, dinoflagellates, and green algae of 50 g C/m^2 as compared to an estimated value of 285 g C/m^2 in Anadyr Stream Water (McRoy et al. 1985).

3.2 INVERTEBRATES

A major factor in determining the suitability of a habitat for a species is food supply. Other factors include cover, substrate, water properties, temperature, light, current speed, and many other physical attributes. The Yukon Delta is an important fishery area in terms of catch and habitat, yet little is known about the distribution and productivity of invertebrates, a primary food of fish and birds, in this area. Kirchhoff (1978) sampled the shallow mudflats (<1 m in depth) just off the delta coast, and collected estuarine epibenthic crustaceans (*Neomysis intermedia* and *Saduria entomon*).

Some other information on aquatic invertebrates of the lower Yukon River can be derived from studies by

Martin et al. (1986) and Wing (1988) on food habits of deltaic fish. Tentative invertebrate habitat relationships can be drawn from analyses of their stomach contents and the known habitat requirements of the dominant food types. Such relationships also provide additional insight on the relative importance of habitat type to resident and anadromous fish. One must be cautious not to conclude too much from this approach, however, because of the multitude of limitations in the data. First, in the absence of direct sampling of habitat types to estimate available prey, it is impossible to ascribe dependency of any of the fish to particularly prominent components of their diets (Martin et al. 1986). We know only what the fish were feeding on just prior to their capture. Information on prey availability within a habitat is not specifically known and can only be surmised from an evaluation of the total prey spectrum indicated by a pooling of food habits data. Second, identification is usually based on hard parts, which presents a bias depending upon the length of time an organism was present in the stomach and its specific digestion rate. Third, linking habitat to food organisms is limited by the level of taxonomic identification. For example, some families of insects, such as Chironomidae (midges), occur in a wide variety of freshwater and marine habitats. Determination of probable habitat requires identification to genus or even species level for this group of insects. However, members of the beetle family, Staphlinidae, are characterized as burrowers in intertidal beaches. The determination of probable habitat for this family is much more certain.

An inventory of stream and coastal invertebrates of the Yukon Delta, based on fish food habits data, is presented in Table 3.1. This list includes the common names of the aquatic invertebrates and their known general habitat relationships. At least 69 invertebrate families have now been reported from the lower Yukon River. The list is preliminary, serving as an indicator of the dominant invertebrates available to local food webs. A separate sorting by deltaic habitat is provided in Table 3.2.

Martin et al. (1986) described a general trend in the prey selection of opportunistically feeding fish in deltaic habitats. Drift and epibenthic insects were heavily fed on by fish in river distributary habitats. Mysids, copepods, and amphipods were major prey species within coastal sloughs, mudflats, and inner delta platform habitats. Farther from the coast, planktonic copepods became more important in fish diets.

The invertebrate drift normally found in rivers during seasons of high discharge includes aquatic pelagic and planktonic forms, terrestrial forms (that have fallen into the aquatic system), and what are usually considered benthic forms. Benthic invertebrates appear periodically in the water column (behavioral drift), or are accidentally swept into the discharge during bottom scour and/or overflowing of lentic systems (catastrophic drift). The drift is therefore derived from a variety of habitats. Their origins are likely to be upstream of the river's mouth or point of capture by deltaic fish.

Based on the habitat requirements of the different invertebrate groups (Table 3.1), the trend noted by Martin et al. (1986) appears reasonable. Different prey species are characteristic of different habitat types. One would expect freshwater forms and forms derived from terrestrial and lentic environments to appear in the drift of the distributaries and coastal sloughs, euryhaline forms to appear in a wide variety of habitat types from freshwater to marine, and strictly marine forms to appear only in the stomachs of fish caught in the mid-delta platform and at the delta front.

Invertebrate drift appears to have a major influence on salmonids in the lower Yukon River. This is suggested by the foraging habits of juvenile chum and pink salmon and the least cisco. Drift insects were prominent in the diet of least cisco and chum salmon in all habitats, including offshore locations near the delta front. Similarly, juvenile pink salmon fed on epibenthic insect larvae in all habitats except the delta front (Table 3.2). The insect drift was probably derived from terrestrial, freshwater, and coastal marine habitats and was dominated by dipterans.

A small number of invertebrate prey appear to be most common in the diets of deltaic fish, reflecting not only relative abundance but their availability and preference as prey. They might be considered as "requisite" prey (Martin et al. 1986) of resident and migratory fish during the summer months. These include (1) Chironomidae (midges), both drift adults (terrestrial) and epibenthic larvae (freshwater and marine–littoral); (2) planktonic cladocerans, consisting of the freshwater forms *Bosmina* and *Daphnia* and the co-existing marine form, *Podon*; (3) the planktonic calanoid copepods *Eurytemora, Epischura,* and *Epilabidocera longipedata* (small calanoids characteristic of estuaries); (4) the epibenthic harpacticoid copepod *Tachidius* (characteristic of estuaries); and (5) epibenthic crustaceans, including mysids (*Neomysis* in coastal waters), amphipods (notably of the family Haustoriidae), and isopods (*Saduria entomon,* particularly in tidal sloughs, mudflats, and inshore waters).

The Chironomidae are a remarkably successful insect group in the Arctic (Butler 1980). They are an exceedingly important component in the diets of juvenile pink and chum salmon (Martin et al. 1986; Wing 1988) and numerous species of waterbirds

TABLE 3.1—Invertebrate occurrence in the Yukon Delta. The species list is derived from fish stomach analysis (Martin et al. 1986). Information on habitats is derived from a variety of sources including Hansen and Richards (1985), Hobbie (1984), Merritt and Cummins (1978), and Reid (1961).

Taxon	Habitat
ROTIFERA	All freshwater habitats.
NEMATODA	All benthic habitats—freshwater, marine, and terrestrial.
ANNELIDA	
Polychaeta	Estuarine, marine; benthic.
Oligochaeta	Estuarine, freshwater; benthic.
MOLLUSCA	
Pelecypoda	
Mya arenaria	Estuarine, marine; benthic.
Macoma sp.	Estuarine, marine; benthic.
ARACHNIDA	
Araneae (spiders)	Terrestrial.
Acarina (mites)	Terrestrial, freshwater; lentic littoral.
CRUSTACEA	
Notostraca (tadpole shrimp)	Freshwater ponds and shallow lakes without fish.
Cladocera	
Daphnia sp.	Freshwater plankton, slow-flowing lotic and lentic.
Bosmina sp.	Freshwater plankton, slow-flowing lotic and lentic.
Podon sp.	Marine, estuarine; planktonic.
Chydoridae	Freshwater lentic, associated with littoral and aquatic vegetation.
Ostracoda	Marine, estuarine, freshwater lotic and lentic, primarily benthic.
Copepoda	
Calanoida	Freshwater, estuarine, marine; planktonic.
Temoridae	Estuarine; planktonic.
Eurytemora herdmanni	
Eurytemora sp.	
Heterocope septentrionalis	
Pontellidae	Estuarine; planktonic.
Epilabidocera longipedata	
Harpacticoida	Freshwater, estuarine, marine; benthic.
Trachidiidae	Estuarine, littoral; benthic.
Trachidius sp.	
Canthocamptidae	Freshwater, estuarine; littoral benthic.
Harpacticidae	Freshwater, estuarine; littoral benthic.
Harpacticus uniremis	
Ectinsomatidae	
Ectinosoma sp.	
Cyclopoida	Freshwater, estuarine, marine; planktonic and epibenthic.
Cyclops scutifer	Freshwater, planktonic and epibenthic littoral.
Monstrilloida	
Monstrillidae	Marine, planktonic.
Balanomorpha	Marine, planktonic.
Mysidacea	
Mysidae	
Neomysis sp.	Marine, estuarine; epibenthic.
Neomysis intermedia	Marine, estuarine; epibenthic.
Mysis littoralis	Marine, estuarine; epibenthic.
Isopoda	
Valifera	
Odoteidae	
Saduria entomon	Marine, estuarine; epibenthic.
Bopyridae	

TABLE 3.1—*Continued.*

Taxon	Habitat
Amphipoda	
Gammaridea	
Gammaridae	Freshwater, estuarine, marine; epibenthic.
Atylidae	
Atylus sp.	
Haustoridae	Marine, estuarine; epibenthic.
Podoceridae	
Dulichia sp.	
Hyperiidae	Marine; planktonic.
Decapoda	
Penaeidea	Marine, estuarine; epibenthic.
Caridea	
Crangonidae	Marine, estuarine; epibenthic.
Brachyura	Marine, estuarine; epibenthic.
INSECTA	
Collembola (springtails)	All aquatic systems in littoral surface film, and terrestrial soil/leaf litter.
Ephemeroptera (mayflies)	
Heptagenoidae	Freshwater; lentic wave-swept shores and lotic riffles.
Plecoptera (stoneflies)	Freshwater; lotic riffles.
Psocoptera (bark lice)	Terrestrial; leaflitter, soil.
Thysanoptera (thrips)	Terrestrial vegetation.
Hemiptera (true bugs)	
Miridae	Terrestrial vegetation.
Homoptera (leafhoppers)	
Phyllidae (2 unidentified species)	Terrestrial vegetation.
Cercopidae	Terrestrial vegetation.
Aphididae	Terrestrial vegetation.
Coleoptera (beetles)	
Staphlinidae	Marine; burrowing in intertidal beaches.
Tricoptera (caddis flies)	All freshwater habitats; lotic and lentic.
Diptera (true flies)	
Tipulidae (crane flies)	Freshwater, estuarine; lentic littoral and lotic pools and riffles.
Ceratopogonidae (no-see-ums)	Freshwater; lentic littoral and lotic pool margins.
Chironomidae (midges)	All freshwater and estuarine habitats, marine littoral.
Chaoboridae (phantom midges)	Freshwater; lentic littoral and lotic pool margins.
Blepharoceridae (net-winged midges)	Freshwater; lotic riffles.
Simulidae (black flies)	Freshwater; lotic riffles.
Culicidae (mosquitoes)	Freshwater; lentic littoral, lotic depositional pools. Estuarine; intertidal.
Mycetophilidae	
Cediomysiidae	
Empididae (dance flies)	Freshwater; lentic littoral, lotic riffles and pools.
Muscoidae (house flies)	Terrestrial.
Sciomyzidae (marsh flies)	Freshwater, estuarine; lentic littoral and lotic pools; larvae in snails, snail eggs.
Dryomzidae	Marine; intertidal, parasitic on barnacles.
Drosophiloidae	Terrestrial.
Ephydridae (brine flies)	Marine; littoral, associated with vegetation.
Muscidae	Freshwater; lentic littoral, lotic riffles and pools.
Hymenoptera (wasps)	Terrestrial.
Scelionidae	Adults are parasitic and enter the water to lay eggs on aquatic insects.
Ichneumonidae	
Tenthredinidae	
Mymaridae	
Platygasteridae	

TABLE 3.2—Occurrence of principal diet components in fish collected from marine, estuarine, and freshwater habitats of the Yukon Delta, June–September 1985. (Based on Table 5–1, Martin et al. 1986.)

	Invertebrate Prey*							
Habitat	PC	EM	EA	EC	ES	DI	EI	EO
Marine–Estuarine								
Delta front	×	×				×		
Mid-delta platform	×	×				×		
Inner delta platform	×	×	×	×	×	×		
Mudflat	×	×	×					
Coastal slough	×	×	×	×	×	×	×	
Minor active distributary	×			×		×	×	×
Freshwater								
Major active distributary	×					×	×	

* PC = pelagic copepods, EM = epibenthic mysids, EA = epibenthic amphipods, EC = epibenthic copepods, ES = epibenthic isopods, DI = drift insects, EI = epibenthic insects (larvae), EO = epibenthic ostracods.

(Holmes 1970, 1972; Jones and Kirchhoff 1978; Gill and Handel 1981) of the Yukon Delta. Becker (1973) suggested that chironomid abundance compensates for lack of size and reported a caloric value of 5.4 kcal/g dry weight. The majority of chironomid larvae are epibenthic detrital feeders. They generally occur in a wide variety of aquatic habitats including small vegetated ponds, depositional sloughs, river channels, intertidal beaches, and mudflats; therefore, those found in the Yukon River drift are probably derived from a multitude of habitats occurring in the delta. The relative importance of these habitats would require sampling of each habitat and taxonomic identification of the chironomids below the family level.

Hansen and Richards (1985) conducted invertebrate surveys in the main channel and sloughs along the middle Susitna River, habitats similar to those in the lower Yukon River. These authors found that the diet composition of juvenile chinook salmon correlated with invertebrate drift, with chironomids being the main food item. Their data suggest that the seasonal distribution of drift insects (chironomids, mayflies, and stoneflies) in the Susitna River is related to the presence of proportionally large numbers of emerging adults. This is consistent with the general patterns found by previous researchers in other parts of the world (Hynes 1970), and one would expect that this also applies to the lower Yukon River.

Butler (1980) studied two chironomid species in tundra ponds near Barrow, Alaska, and found them to have high reproductive synchrony and extended (7-year) life cycles. He observed peak emergence periods in July in tundra areas studied between Barrow and Prudhoe Bay. Hansen and Richards (1985) found that, in the Susitna River, numbers of mayflies and stoneflies in the drift peaked in mid-June and mid-August. Emergence patterns on the Yukon Delta probably resemble those of the Susitna River at least temporally. Martin et al. (1986) reported chironomids as major prey of fish throughout the summer, presumably indicative of an ongoing emergence process. The lack of more quantitative information from the Yukon River makes additional comparisons of species and seasonality exceedingly tenuous. In general, Butler (1980) and other others have found chironomid population sizes in the Arctic to be primarily controlled by environmental conditions (especially wind and temperature) for emergence and oviposition.

Increased drift abundance in a river or stream can be directly correlated with discharge velocities (with associated bottom scouring) and conditions of receding water (Minshall and Winger 1968; White et al. 1981). Hansen and Richards (1985) found that naturally fluctuating flows of the mainstem Susitna River appeared to increase total drift in side channels and side sloughs and, subsequently, the drift food supply for juvenile chinook salmon. This may also be happening in the lower Yukon River, but with respect to pink and chum salmon, their residency in such rearing areas is inconsequential and juveniles may move downstream in the swifter moving waters in the middle of the river's channel (Martin et al. 1986). Becker (1973) reported that under conditions of high Columbia River discharge, the quantity of drift organisms passing downstream per unit of time is much higher than during periods of low flow. He argued that there are energetic benefits to juvenile chinook feeding on smaller, more easily captured chironomids, given the higher energy costs of locating and capturing larger prey. Many studies have shown prey selection in juvenile salmon to be dependent on the size of the salmon. Size selection may, in part, explain the observed reliance on chironomids by young salmon on the Yukon Delta.

3.3 FISHERIES ECOLOGY

Prior to OCSEAP's surveys of Yukon Delta nearshore fish (Martin et al. 1986, 1987), little information was available from this area. The commercial and subsistence salmon fisheries in the river are economically important and much research is conducted annually by the ADFG in conjunction with their management. Offshore surveys in Norton Sound were originally conducted by Wolotira et al. (1979) and the area is now sampled regularly by the National Marine Fisheries Service as part of their resource assessments for the Bering Sea. The offshore surveys have been complemented by nearshore and subtidal studies in other parts of Norton Sound and Kotzebue Sound (Barton 1978; Merritt and Raymond 1983). Information on subsistence and commercial use patterns of fish in the lower river communities has been reported by Barton (1977), Hemming et al. (1978), Wolfe (1981), and Nunam Kitlutsisti (1982).

The regional importance of Pacific salmon provided focus to the OCSEAP research (Martin et al. 1986, 1987). Although very little spawning by Pacific salmon occurs in the lower Yukon River, it was assumed that delta waterways would be suitable rearing habitat for presmolt salmon. Given the similarity of this research to juvenile salmon migration studies in the Columbia River and its estuary (Johnsen and Sims 1973), a small-meshed purse seine was selected as the primary gear in 1985. In 1986, gear comparisons between the purse seine and a tow net revealed similar catch rates, and for ease in deployment the latter gear was used for sampling in 1986. Other gears (fyke nets, beach seines, and gillnets) were used throughout the surveys to sample salmon and nonsalmonid species occurring in the various Yukon Delta habitats.

Fish were collected from an area extending over 150 km of the delta coastline and from 40 km upriver to 30 km offshore (Fig. 3.3). Although this remains the most comprehensive survey of the lower Yukon River, the fishery data were collected over a large geographic area and most sites were only sampled a few times (Martin et al. 1987). In 1986 the effort was limited in order to provide more information on chinook and chum salmon outmigration and estuarine residency, to obtain additional estuarine fish collections in coastal habitats off the South Mouth of the Yukon River, and to relate the catch data to the physical environment.

The following results of the OCSEAP surveys and other relevant research emphasize the new information gained, and the current condition of the Yukon River fishery, stocks, and management plans. Discussions of other fish species follow those on salmon. Figures 3.4 and 3.5 depict fish sampling locations in 1985 and 1986, respectively. Habitat partitions were determined on the basis of differences in elevation and location relative to the coast (Table 3.3). These factors are expected to greatly influence the extent of seawater mixing, river flooding, water clarity, degree of water influence, and water velocities (Martin et al. 1986). They also correspond to the riverine and estuarine zonation scheme of Truett et al. (1984).

3.3.1 Salmon Fishery

All five species of Pacific salmon (*Oncorhynchus* spp.) are found in the Yukon River. Chum salmon are most abundant, followed by chinook, coho, pink, and sockeye. Commercial fishing for chinook salmon began in 1918 but other species were not commercially harvested until the mid-1970s (Whitmore et al. 1987). Today, most of the Alaskan catch is reported from the lower 160 km of the Yukon River. Lower-river fish are taken in drift net and set net fisheries. Set nets and fishwheels are the primary gears used in upper-river salmon fisheries. These gears are also the ones employed in subsistence fisheries which also occur in the major fishing areas of the river.

Yukon River salmon managers divide the river into Upper Yukon and Lower Yukon areas. Each area is further divided into three districts (Fig. 3.6). The Lower Yukon area (Districts 1, 2, and 3) includes the coastal waters of the Yukon Delta and extends 484 km upriver to Old Paradise Village. The Alaskan harvest (chum, chinook, and coho) averaged 892,888 and 117,218 fish in the Lower Yukon and Upper Yukon areas, respectively, for the 5-year period 1982–86. (Unless indicated otherwise, salmon catch statistics have previously been reported by Whitmore et al. [1987].) Upper Yukon area fishermen sold more than 200,000 lb. of unprocessed roe per year during this 5-year period. Approximately 800 commercial fishermen (665 in Districts 1–3) and 20 processors participated in the fishery. The ex-vessel value of the fishery for 1982–86 averaged $6.6 million annually.

Subsistence harvest information is also available for the Yukon areas for 1982–86 (Whitmore et al. 1987). The average Alaskan subsistence harvest during

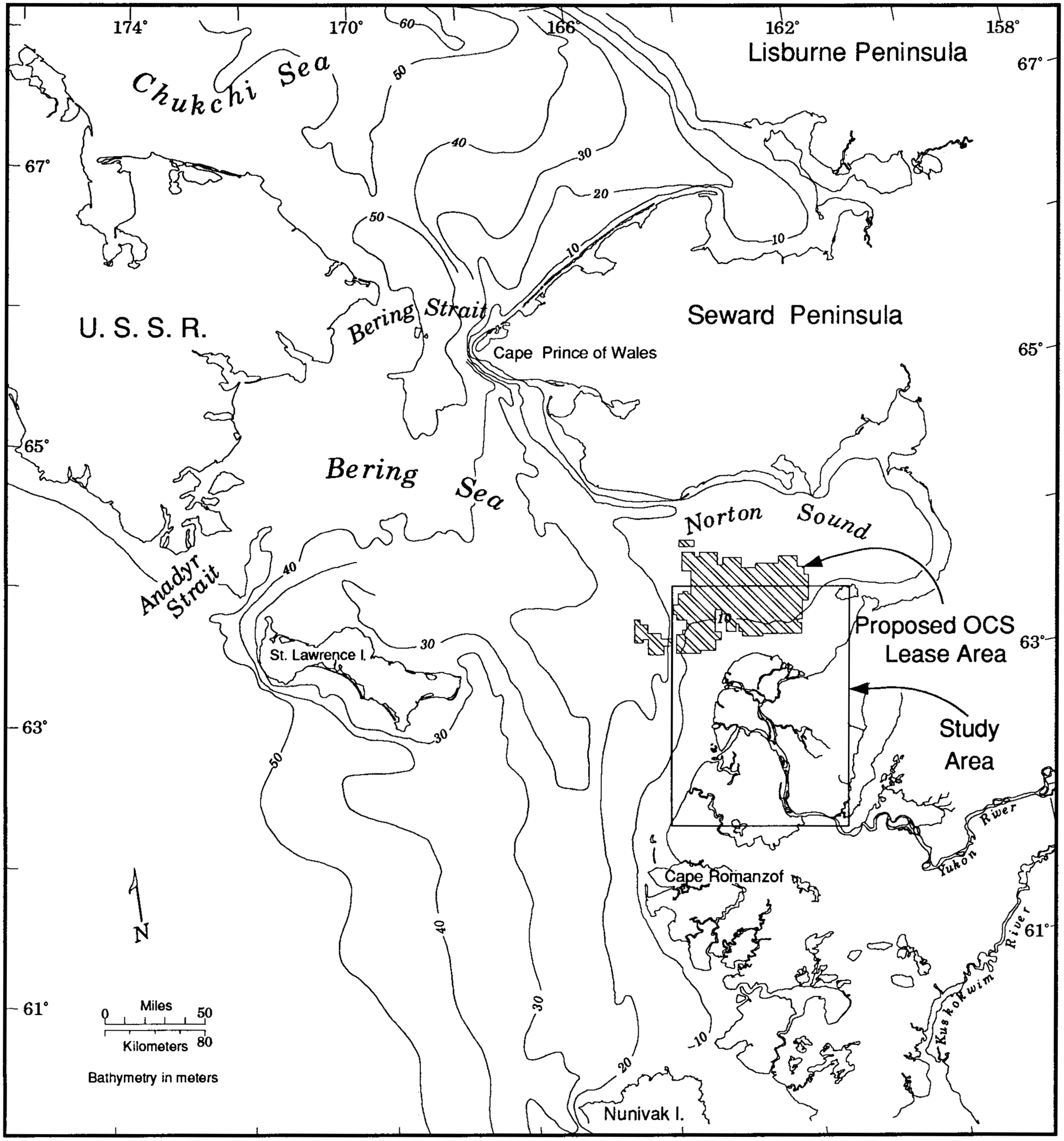

FIGURE 3.3—Location of the Yukon Delta fishery study area relative to proposed OCS leasing area in Norton Sound. (Adapted from Martin et al. 1987.)

that period was 507,927 fish. Of these, almost 400,000 were caught annually in Upper Yukon area districts (Table 3.4).

The total Alaskan Yukon River harvest in 1987 was 574,209 salmon, composed of 131,971 chinook and 442,238 summer run chum (Whitmore et al. 1987). More than 120,000 lb. of roe were harvested in the summer chum roe-directed fishery. The total catch was estimated to be valued at $7,161,500. Ten buyer-processors operated on the lower Yukon River in 1987. Projections of subsistence harvest information estimate Alaskan catches at 45,000 chinook, 225,000

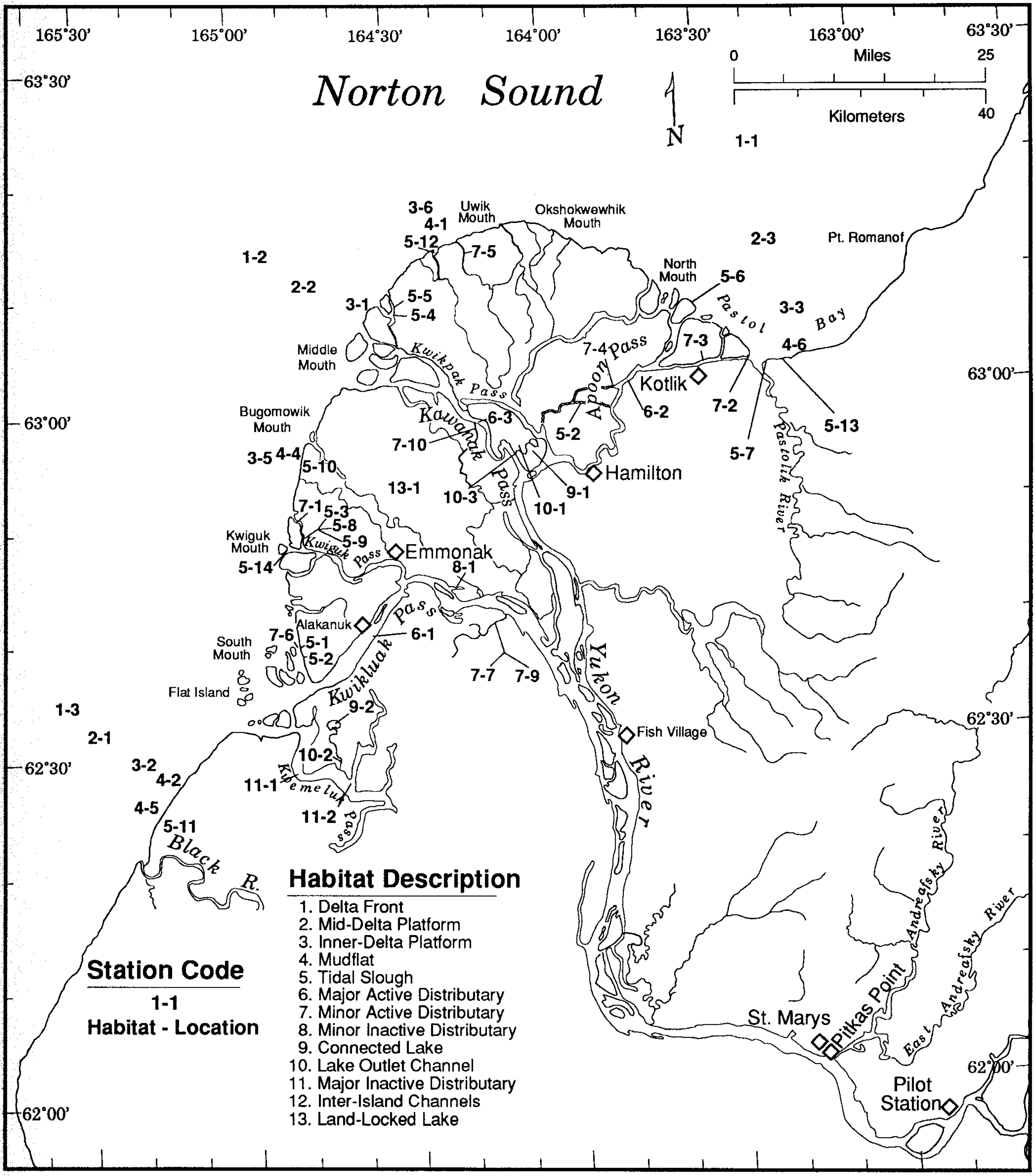

FIGURE 3.4—Location of sample sites for the summer 1985 survey of the Yukon Delta. (Adapted from Martin et al. 1986.)

summer chum, 175,000 fall chum, and 35,000 coho. More than 1,000 families from 37 communities (excluding the Fairbanks area), representing 9,000 people, are estimated to participate in Yukon River subsistence salmon fishing in Alaska (Whitmore et al. 1987).

Annual Yukon River salmon harvests have exceeded 1.1 million fish since 1974, and averaged about 1 million during 1982–86. The ADFG statistics (numbers of fish caught) indicate an average total Alaskan and Canadian harvest of 1,562,447 salmon (Table 3.5).

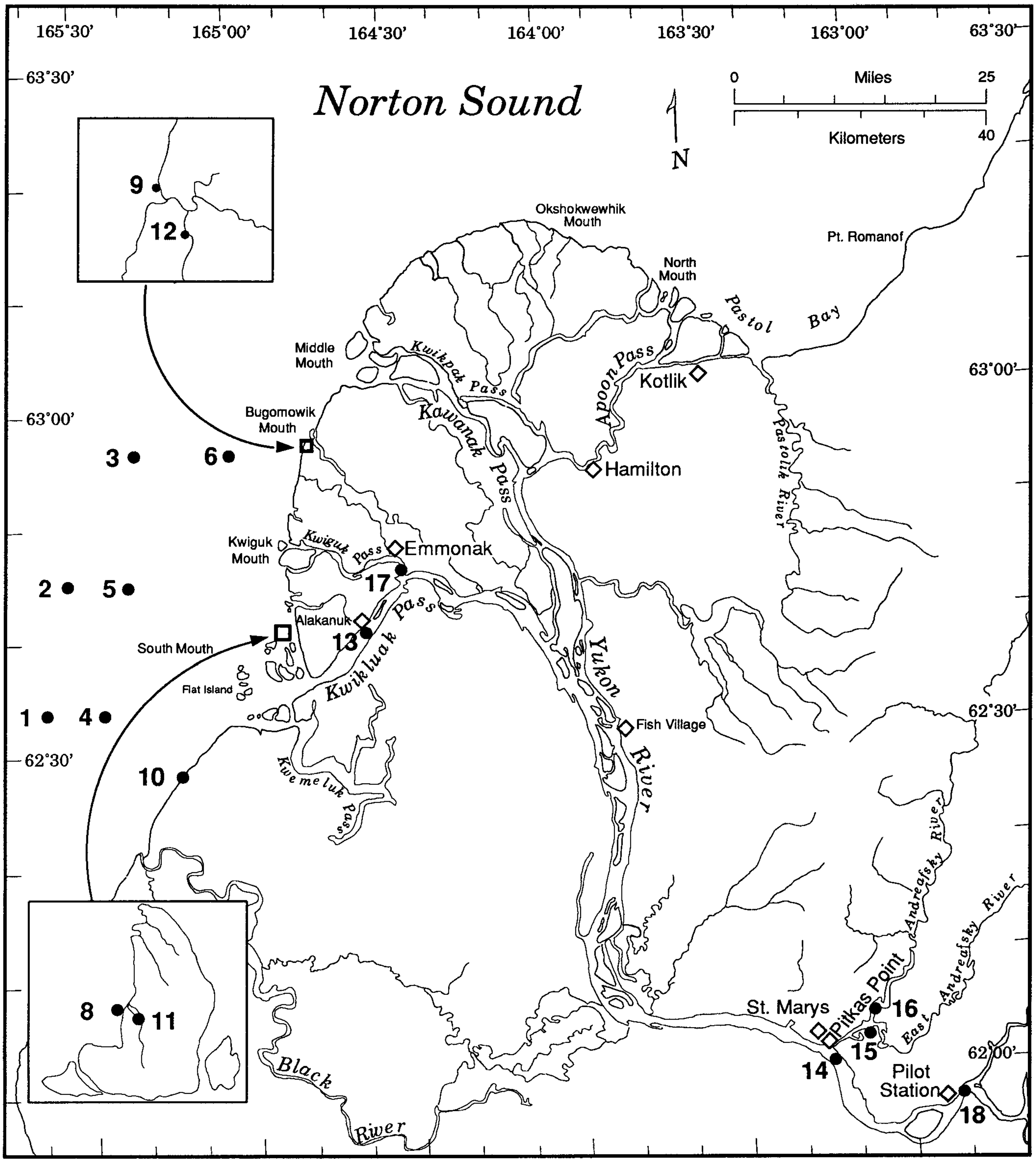

FIGURE 3.5—Location of sample sites for the summer 1986 survey of the Yukon Delta. (Adapted from Martin et al. 1987.)

Whitmore et al. (1987) estimated an average yearly catch of 1,795,652 salmon for the 5-year period 1982–86. This estimate of total salmon catch incorporates summer and fall chum roe-directed fishery catches not discussed above. Roughly 1 lb. of unprocessed roe is extracted from each female harvested; the most recent 5-year average (1982–86) is 200,331 lb. of roe per year. Catch data for pink and sockeye salmon have not been recorded because their numbers are too few to contribute significantly to the total catch, but

TABLE 3.3—Aquatic habitats of the Yukon Delta.

Habitat	Description
Delta platform	The shallow water zone that extends from the outer edge of the coastal mudflats to the approximate outer limit of the shorefast ice in winter. This zone may extend 20–30 km seaward from the coast and may be only 3 m deep (range, 3–14 m). The delta front is approximately 5 km wide.
Inner delta platform	A portion of the delta platform located 4-8 km from the coast.
Mudflat	The narrow intertidal zone extending from the emergent coastal edge to as far as 1–1.5 km offshore. Water depths range to 1 m at high tide.
Tidal sloughs	Small interconnecting or dead-end channels that may connect to the sea during spring flooding, and are closed to the sea or other sloughs during the low flow period. The slough banks are usually covered with dense stands of marsh grasses that are covered at high tide.
Tidal channels	Small dendritic waterways that extend into and drain marsh areas during low tides.
Active distributaries	River channels that extend seaward and as subsea (summer) or sub-ice (winter) channels. *Major* distributaries include large river channels 0.5–3 km wide that flow year round. *Minor* distributaries are smaller, less than 0.5 km wide, and flow intermittently.
Inactive distributaries	Small interconnecting or dead-end drainage channels that may connect lakes or other river sloughs with a major distributary or slough. Inactive distributaries may be categorized as *major* or *minor,* with channel sizes corresponding to those described for active distributaries.
Lake	Lentic environment surrounded by the delta marsh that may or may not have an outlet stream. Three sub-habitat types are identifiable including *lake outlet,* a small channel connecting a lake with an inactive distributary or slough; *connected lake,* a lentic environment connected to an active distributary or slough by an outlet channel; and *land-locked lake,* a lentic environment surrounded by the delta marsh with no outlet channel.
Inter-island channels	Small active channels that separate islands and bays along the delta coastline.

they may explain part of the differences in the total use estimates. Both estimates are undoubtedly conservative as they do not include recreational catch.

3.3.2 Salmon Stocks

The Yukon River may be the single largest producer of chinook and chum salmon in Alaska. Research aimed at management of these populations has been largely confined to adults and has resulted in good information on various characteristics including age, sex, size, run (catch plus escapement) timing and composition, and identification of spawning sites, for chum and chinook salmon (Martin et al. 1986). The life history of Pacific salmon is well documented and can be found in many literature sources such as Ellis (1977).

Two runs of chum salmon are recognized in the Yukon River, a summer run and a fall run. Whitmore et al. (1987) described major run attributes. Summer runs enter the river about 6 weeks earlier than fall chums and individual fish are slightly smaller in weight (1–3 lb. lighter). The maturation process in summer chums is well advanced in fish captured in the lower river early in the summer (June through mid-July) compared with those taken later in the season. Maturation state is indicated by the fish's coloration; summer chums tend to change color rapidly, and fall fish remain silvery. The spawning locations of the two runs are distinct: summer chums spawn primarily within the lower 965 km of the river, and fall chums above this in spring-fed feeder tributaries of the main stem.

TABLE 3.4—Alaskan subsistence harvest (number of fish) of Yukon River salmon, 5-year average, 1982–86 (Whitmore et al. 1987).

	Summer		Fall	
Area	Chinook	Chum	Chum	Coho
Alaska	41,023	257,564	174,231	35,109
Lower Yukon	14,023	59,187	13,109	110,045
Upper Yukon	27,004	198,377	150,928	397,882

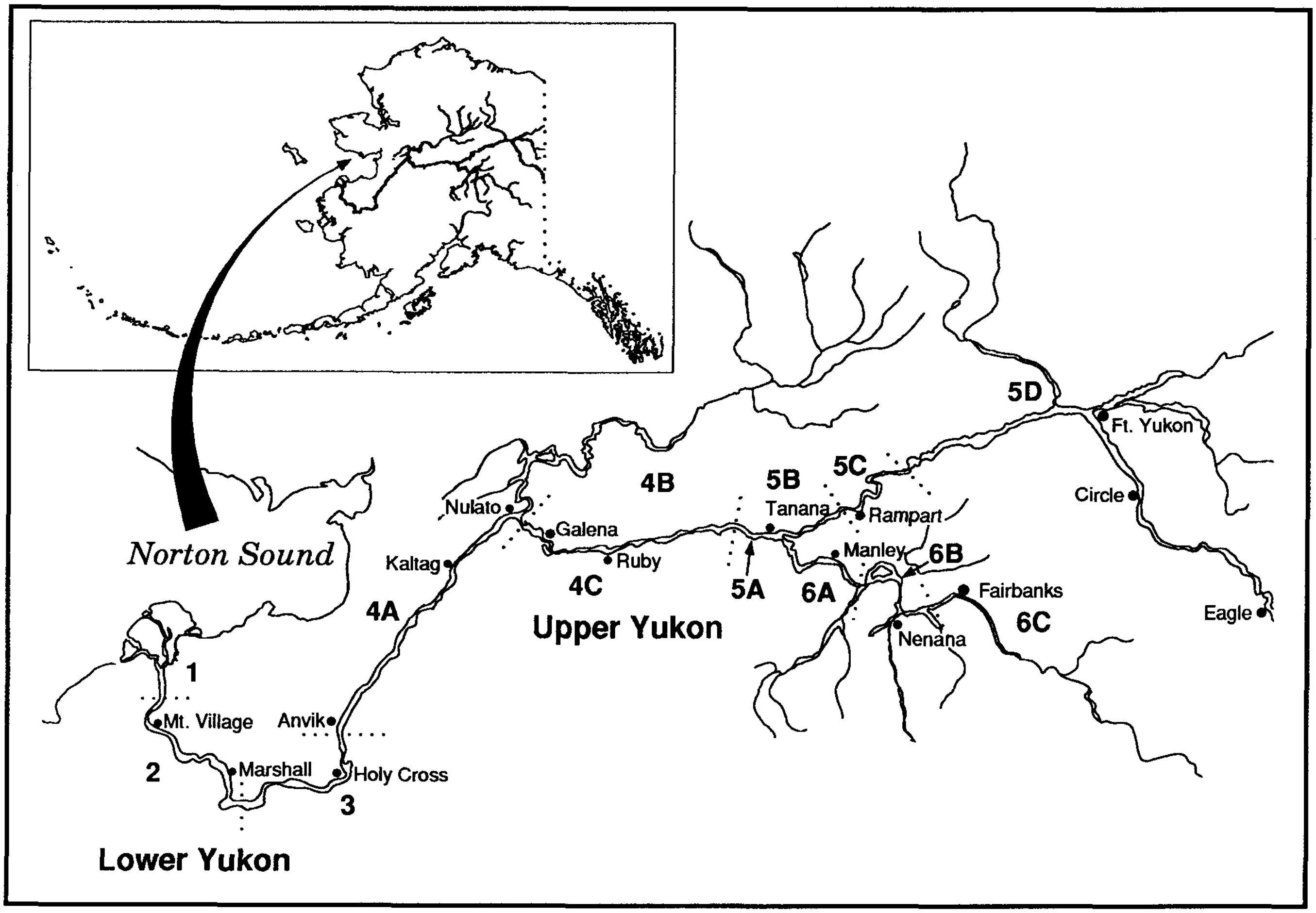

FIGURE 3.6—Yukon Management Area Districts 1–6. (Adapted from Whitmore et al. 1987.)

Merritt and Raymond (1983) suggested that the larger size and higher fat content are adaptations to the longer river migrations (during which fish do not feed) and that their preference for springs (warmer than ambient water temperatures in winter) is an adaptation to compensate for the later spawning period. Finally, summer chums are much more abundant than fall chums.

TABLE 3.5—Alaskan and Canadian commercial and subsistence harvests of Yukon River salmon, 5-year average, 1982–86 (Whitmore et al. 1987).

	Commercial		Subsistence	
	Alaska	Canada	Alaska	Canada
Chum				
Summer run	606,669	0	257,564	0
Fall run	228,441	21,489	174,231	4,701
Chinook	127,523	10,984	41,023	7,240
Coho	47,473	0	35,109	0
Total	1,010,106	32,473	507,927	11,941

As noted above, spawning periods vary by species and drainage but generally occur between June and December. The timing of spawning runs is also variable and appears to depend on the weather (Whitmore et al. 1987). Chinook begin returning in late May and early June; most pass the lower river fishery by early July. Summer chums begin entering the river in early to mid-June, and fall chums follow from mid-July well into September. Coho are usually present in the river by early August, with runs continuing into September.

There is no significant spawning by salmon downstream of Mountain Village and Nulata Hills. In Alaska, chinook spawning populations are widely distributed in the Yukon River, with major spawning grounds on the Andreafsky, Anvik, Nulata, and Chena rivers. In Canada, chinook spawn in greatest numbers in the Big Salmon and Nisutlin rivers. According to Whitmore et al. (1987), chinook escapement trends from 1976 through 1981 were consistently above other years and stocks may have been overexploited in river fisheries.

The majority of chinook returning to the Yukon River are 6-year-old fish, although 5- and 7-year-olds are commonly harvested (Whitmore et al. 1987). The 1982 brood year was determined to be "average to below average" in escapement, the 1983 brood year "near average," and the 1981 year class "above average." The chinook harvest for 1988 was forecast at between 70,000 and 100,000 fish (Whitmore et al. 1987).

The main spawning area of summer chums is in the Anvik River. Other important spawning grounds include the Andreafsky, Nulata, Rodo, Salcha, and Hogatza rivers. The status of the summer run population is presently thought to be "good," as escapement estimates have not declined in recent years (Whitmore et al. 1987).

Summer chums return primarily as 4- and 5-year-old salmon. The 1984 summer chum escapement was determined by the ADFG to be "above average." Because of the low numbers of returning 4-year-olds in 1987, indicative of poor survival of the 1984 cohorts, the expected returns of 5-year-olds in 1988 were expected to be below average. Assuming average survival of the 1984 cohort, the 1988 catch was expected to be "average to above average" and similar to the 5-year average (600,000 fish and 200,000 lb. of roe).

The Porcupine River drainage in Alaska and Canada, the Chandalar and Tanana in Alaska, and the upper Yukon River in Canada provide the major spawning habitats for fall-run chums (Whitmore et al. 1987). These runs can be distinguished by variations in arrival of stocks at the spawning sites. The ADFG reports serious declines in the numbers of returning fall chums for most spawning areas. Escapements were especially poor during 1982–84 (Whitmore et al. 1987).

Yukon River fall chum runs are composed mostly of 4-year-old salmon. Escapements in 1984 were below average and a "below average" run was expected in 1988 (Whitmore et al. 1987). In fact, area closures were an expected requirement for 1988 in order to limit the Alaskan fishery.

Coho salmon returns are composed mainly of 4-year-old fish. Available escapement records do not provide adequate geographic coverage to forecast the strength of returns for 1988. Coho catch rates will be affected by regulations imposed by the ADFG on fall chum fisheries. Whitmore et al. (1987) indicated the 1988 coho catch could be as high as 50,000 fish.

3.3.3 Juvenile Salmon Outmigration

The first reported study of juvenile salmon outmigration in the Yukon River was that of Barton (1983). In 1976 and 1977 he observed peak chum salmon outmigration periods in mid-June at water temperatures of 9–11°C. Too few chinook salmon were sampled to permit much discussion about the timing of their outmigration. Limited coastal sampling indicated that juveniles were present near Flat Island through mid-July. Barton (1983) concluded that estuarine residence was probably of short duration.

Ice in the lower Yukon River in 1985 prohibited sampling of smolts until 14 June (Martin et al. 1986). Low catches of chinook suggested that the peak migration period had already passed. The next year sampling was initiated on 1 June and juvenile chinook were captured from that date through mid-August, with the highest catch per unit of effort (CPUE) rates observed in late June. The existing literature on the timing and size of chinook smolts from the Yukon and other Alaskan rivers (Table 3.6) indicates that outmigration may begin as early as April (e.g., Delta River) and continue into September (Martin et al. 1987). Timing is probably a stock-dependent phenomenon. Variations in smolt abundance in the lower river may reflect not only differences in distances traveled downstream (as much as 86 km/d) but also annual variations in the weather. As a result, several peaks could occur; for example, peak chinook outmigrations from the Delta River may occur in May, again in late June, and possibly later in the season (Martin et al. 1987).

Age composition determinations from length frequency data indicate that June-caught chinook were mostly 1-year and older-aged juveniles (Martin et al. 1987). Most salmon captured in June 1986 were larger than 69 mm. Catches reported later in the summer, in July and August, were composed of various-aged chinook smolts which included younger fish than were seen in June. Fork length measurements in late summer ranged from 83 to 123 mm (Martin et al. 1987).

A peak outmigration period of 20–30 June 1985 was reported by Martin et al. (1986). However, because ice delayed sampling that year, large numbers of smolting chum salmon could have been missed. Bird (1980) reported peak outmigration of chum fry from the Noatak River in Kotzebue Sound between 14 and 24 June. In 1985, chum fry were captured in various delta habitats from mid-June until mid-September. In 1986, the highest CPUEs were reported on 18 June (Martin et al. 1987). In view of these results, and others on the timing and size of chum smolts (Table 3.7), Martin et al. (1987) concluded that the outmigration period for chums commences prior to ice breakup and extends into early autumn. The authors noted that peak outmigration timing on the Yukon River is later than reported for the species in rivers farther to the south.

Unlike other chum-producing systems, smolt size at the time of seaward migration down the Yukon River varies widely and appears to be a function of distance of the spawning site to the Bering Sea. In June 1986 more than one size mode in chum fry was reported

TABLE 3.6—Outmigration timing and size at outmigration of chinook salmon smolts from the Yukon River and its distributaries, 1986. (Data extracted from Martin et al. 1987.)

River	Distance from mouth of Yukon River (km)	Outmigration date			Mean length (mm)	N
		From	To	Peak		
Yukon	2,462	21 May*	23 Jun	29 May	76.3	130
		26 May	1 Jun	28 May	88.0	31
Delta	1,659	12 Apr	16 May	28 Apr 14 May	93.0	22
Salcha	1,553	16 May*	8 Jun*	26 May 4 Jun	73.0	488
Chena	1,496	14 May*	20 Jun	1 Jun	76.7	51
		3 May	30 May	9 May	79.6	187
		7 May	23 May	14 May	86.2	22
		4 May	16 May	11 May	75.0	—
Hodzana	1,443	2 Jun	17 Aug	5 Jun 10 Jul	78.8	57
Clear Creek	1,380	30 Apr*	22 May	8 May	71.3	38
Yukon	101	8 Jun	7 Jul*	13 Jun	96.0	14
Yukon	25	4 Jun*	8 Aug*	18 Jun	96.8	313

* Outmigration was in progress when the sampling started or ended.

by Martin et al. (1987), including a group of very large fry (average fork length = 60 mm) and another of smaller fry (average FL = 35 mm). Although juvenile chums were captured throughout the summer, the larger-sized smolts were most abundant in June and may represent fall-run stocks. Martin et al. (1987), assuming that these were fall-run fish and that they emerged from the redds in April, calculated that an average growth rate of 0.3–0.8 mm/d would be required to attain a 60-mm size in June. In the lower river, summer-run stocks emerge from the gravel in mid-May (Buklis and Barton 1984). Much less time would be required for these salmon to reach the coast, which may account for the smaller-sized fry in June (Martin et al. 1987). A small-sized group of unexplained origin, possibly summer-run fish, was also observed in August 1986.

The timing of pink salmon outmigration, previously unreported for the Yukon River, was detectable in the 1985 survey data (Martin et al. 1986). Some outmigration may have been under way prior to ice breakup and was completed by early August. Too few pink salmon were captured to identify a peak in the outmigration. Pink salmon smolts ranged in size from 30 to 40 mm.

3.3.4 Use of Deltaic Habitats by Juvenile Salmon

The apparent lack of salmon in many delta habitats, other than major river channels and open coastal waters, suggests they are relatively unimportant as juvenile rearing habitat, or are underutilized (Martin et al. 1986, 1987). Early marine residency is a critical phase in the life history of salmon. Many scientists believe that survival during this period is a major determinant of future year-class strength and that daily mortality rates are highly variable (Healey 1982*a,b*; Bax 1983). Density estimates of juvenile chinook salmon in the lower Yukon River and adjacent coastal waters (calculated from catch data of Martin et al. 1986) in mid-June 1985 ranged from 40 to 1,150 fish/km^2. The highest densities occurred in the main river and its distributaries, with fewer fish captured at the coast. One month later, relative abundance estimates ranged from 0 at some locations in the lower river to 86 fish/km^2 at the delta front. The indices demonstrate the following trends in habitat use by juvenile chinook: (1) a relatively brief period of use of delta habitats (late May to mid-July); (2) diminishing importance of the delta to smolts with time; and (3) a general pattern

TABLE 3.7—Outmigration timing and size at outmigration of coho salmon smolts from the Yukon River and its distributaries, 1986. (Data extracted from Martin et al. 1987.)

River	Distance from mouth of Yukon River (km)	Outmigration date			Mean length (mm)	N
		From	To	Peak		
Yukon	1,659	17 Apr	27 May	24 Apr	34.2	92
		2 Apr	25 May*	28 Apr 18 May	34.6	1,426
		9 Apr	20 Apr	9 Apr 18 Apr	32.0	72
Salcha	1,553	16 May*	8 Jun*	—	39.5	106
		10 May	30 May	20 May	34.6	27
Chena	1,496	22 May	3 Jul*	12 Jun	41.3	142
		8 May	27 Jun	8 May	36.2	139
		6 May	7 Jun	21 May	35.9	228
		2 May	18 May	11 May	35.0	—
Hodzana	1,443	2 Jun	24 Aug*	5 Jun	39.2	474
Tanana	1,378	9 May*	22 Jun*	2 Jun	35.8	274
		14 May*	5 Jun	22 May	36.5	201
Rodo	719	—	13 May*	—	33.6	7
Bear Creek	636	22 May	20 Jun*	—	38.2	69
Anvik	530	22 May	26 Jul*	—	36.0	—
Innoko	512	—	25 May*	—	33.6	7
Yukon	101	7 Jun*	2 Jul	13 Jun	41.0	265
Yukon	25	4 Jun*	8 Aug*	18 Jun	43.7	1,078

*Outmigration was in progress when the sampling started or ended.

of increased use of the delta offshore habitats relative to other types available to the species (e.g., mudflats and tidal sloughs). Similar patterns in distribution and abundance were found by Martin et al. (1987).

The observed coastal dispersal of chinook salmon smolts probably reflects the river's influence on emigration. Their seaward migration overlaps the period of maximum river discharge, when the river and its freshwater plume extend far off the coast. Chinook smolts appear to be carried as far as 20–30 km offshore in strong river currents. Away from the coast, as currents diminish, some salmon may be able to migrate, or be passively diverted, into the ice gouge channels of the delta platform. During breakup and periods of high freshwater discharge, most salmon may be carried past prospective rearing habitats by strong currents in the lower Yukon River.

Size-related offshore movements of juvenile chinook salmon have been documented in estuaries of the Pacific Northwest (Healey 1980; Myers 1980). Juvenile chinook remain in coastal estuaries until a threshold size of 70 mm is reached. Only when this growth is attained will the juvenile fish extend their migration offshore. Martin et al. (1987) found chinook fry to be of similar size (fork length, 70 mm) upon their entry into the Bering Sea. Growth achieved by the fish during their downstream migration may compensate for the brief residency in coastal habitats. Mortensen and Wertheimer (1988) noted that while size may play an important role in determining the timing of offshore migration in systems where migrational events are temporally consistent from year to year, other environmental cues may be involved.

Juvenile distribution and abundance in delta habitats are influenced by turbidity. Citing various authors, Martin et al. (1987) indicated that surface water quality (for visibility and feeding) may be the most important factor in determining the vertical distribution of *juvenile salmon in estuaries (upper 5 m).* Murphy et al. (1987) reported that turbidity had only a secondary influence on habitat use by fry in lower reaches of the Taku River in southeast Alaska. In the Yukon Delta, the outer delta platform and delta front were the only habitats available to salmon where visibility was greater than 0.5 m (Martin et al. 1987). Although turbidity may affect primary production and impair feeding (Murphy et al. 1987), it may also provide refuge from potential predators.

Current velocities were found to be the primary influence on habitat use by juvenile salmon in the Taku River. Murphy et al. (1987) observed juvenile chinook and coho salmon in all lower river habitats except those areas where river currents exceeded 30 cm/s. Chinook densities were highest in slow to moderate currents of 1 to 20 cm/s. During periods of peak flow, currents through the lower Yukon River are apt to exceed 600–700 cm/s, with the greatest amount of transport through the South Mouth. Coastal currents within 25 km of the Yukon Delta, over the delta platform and near the front, average about 12 cm/s to the north during summer months. Tidal energies are greatly dissipated at the delta front by frictional forces associated with topography.

Hydrographic conditions over the coast and out to the delta front are characterized by a very fresh surface layer (salinity 1 ppt) over a more saline layer (less than 25 ppt). Martin et al. (1987) reported that the highest chinook CPUEs were off the coast when temperatures ranged between 8 and 10 °C at intermediate salinities of 5–15 ppt. These conditions correspond to the optimal temperature (9–14 °C) and salinity conditions for saltwater transition by juvenile chinook reported by Levy and Northcote (1982).

The transition, or acclimation, period entails the adjustment juvenile salmon must undergo upon entering the sea in order to be able to regulate water and salts in body tissues and fluids. Kepshire and McNeil (1972) found that this physiological adaptation to marine environments in chinook fry was triggered by early exposure to low salinity waters. They were able to experimentally demonstrate a higher growth rate in premigratory chinook rearing in brackish waters (0–17 ppt) than those exposed to higher salinities. The metabolic costs for osmoregulation in more marine environments may be responsible for slower growth rates.

Food availability might also have influenced habitat use by juvenile chinook salmon. According to Vannote et al. (1980), in large river systems the food base of fish is decompositional, resulting from the recycling of organic matter through invertebrate food webs. Reliable food habits information for chinook from the Yukon Delta is not available. The few samples that were obtained indicate that aquatic insects, and possibly isopods, are important foods.

The network of ice gouge channels across the delta platform serves to extend the amount of coastal estuary available for rearing by chinook salmon a considerable distance offshore, and thus compensate for the observed underutilization of other riverine habitats. These channels may serve as low-current refuges (Macdonald et al. 1987), or provide habitat similar to tidal channels in other estuaries. Tidal channels consist of dendritic waterways extending into and draining marsh areas. They are important transitional habitat for juvenile chinook (and other salmonids) because they provide a mechanism for the fish to maintain a position close to abundant crustacean and insect foods of marshes without being flushed downstream (Levy and Northcote 1982)

Chum salmon were captured in all coastal habitats during the 1986 season (Martin et al. 1987). It is difficult to evaluate the value of tidal slough and mudflat habitats to chum salmon in view of the limited sampling efforts in these areas and consequent low overall reported catch. Even so, on 14 June 1986, fish densities of 20,000–40,000 fish/km² were reported from a delta tidal slough site. This abundance was an order of magnitude higher than reported for other habitats in this period (Martin et al. 1987). The importance of nearshore marshes for estuarine growth and transition elsewhere in the salmon's range (Congleton and Smith 1977; Simenstad and Salo 1980) appears to be confirmed for the Yukon Delta in the high catches reported by Martin et al. (1987). Chum salmon are able to adjust quickly to seawater, and their abundance in the delta's sloughs and other coastal areas may be influenced by tidal stage (Iwata and Komatsu 1984). This may partially explain the highly variable CPUEs for chum fry in the slough habitats. Tidal effects were noted by Martin et al. (1986), as juveniles were captured over wider portions of active distributaries, adjacent tidal channels, and lake outlet streams during periods of high tide.

Chum salmon densities peaked in the coastal habitats of the delta in mid-June in 1986 and 1987. In offshore waters of the delta front, they were highest in late June. A declining trend in catches from north to south at the delta front was observed during periods of high smolt abundance (Martin et al. 1987). This pattern of coastal dispersal could reflect the effect of wind on preferred habitat availability (in the river's plume), and not a directed migration.

Most juvenile chum salmon sampled at the delta front and platform habitats were 40–50 mm (FL) long. Similar length frequencies were reported by Bird (1980) for fry leaving the Noatak River in Kotzebue Sound. In the Pacific Northwest, Simenstad and Salo (1980) reported that chum fry move into inshore habitats of Hood Canal estuary when they are 30–40 mm long. Upon attaining a size of 40–50 mm in the spring, they move from inshore to neritic habitats. Size-related movements were related to size-dependent aspects of prey utilization and food availability. A residence period of about two weeks in inshore and neritic habitats by chum was hypothesized (Simenstad and Salo 1980). Chum salmon moving down the Yukon River appear to be larger at entry into the estuary, enabling them to be less dependent on coastal sloughs and other inshore habitats than chum salmon studied in more southern regions. Growth of fish during passage through the river may correspond to that associated with inshore residency elsewhere.

Martin et al. (1987), citing various authors, reported that chum salmon generally tend to move from inshore (marshes, sloughs) to offshore areas upon reaching sizes of 40–75 mm (FL), and farther seaward to the open ocean at sizes of 70–130 mm. Merritt and Raymond (1983) noted that while the peak outmigration period of chums in the Noatak River is later than reported for rivers of southeastern and southcentral Alaska, they appear to leave nearshore waters at roughly the same time (by mid-July). This may also reflect their relatively large size upon leaving the river. Major pathways of seaward migration in Norton and Kotzebue sounds remain poorly known and few studies have been conducted offshore. Barton (1978) captured five juvenile salmon off the northwest coast of the Seward Peninsula in September 1976; only one chum salmon was taken, and measured 188 mm (FL). A cruise report for the 1986 ISHTAR research indicates that small numbers of juvenile salmon (chum, chinook, pink, and coho) were sampled off the Yukon Delta and in Norton Sound (Tripp 1986). However, no information was provided on size of the fish sampled.

The small numbers of chum salmon sampled in Yukon Delta inshore habitats reflect a diminished importance of these habitats relative to what has been observed for the species elsewhere. Like the outmigrating chinook, chum fry may be transported far offshore of the river mouth and there may be a brief overlap in habitat use between the two species. Levy and Northcote (1982) noted an overlap in marsh residency by chums and chinook in the Fraser River estuary. Merritt and Raymond (1983) observed that chum fry were most abundant in Kotzebue nearshore waters at locations where currents were 6–9 cm/s. Because chum salmon fry are sight feeders and feed selectively, good visibility is required for successful feeding (Merritt and Raymond 1983) and would be a requirement of rearing habitat. Bailey et al. (1975) reported that feeding by chum salmon at Traitors Cove, southeastern Alaska, was most active in river areas where current speeds were less than 10.7 cm/s and stopped at velocities above 19.9 cm/s. Similar conditions may affect coastal areas viewed as extensions of the river habitat.

3.3.5 Estuarine Residence

Estuarine residence was described for juvenile chum salmon taken in the Yukon Delta in 1986 by Martin et al. (1987). Residence period was determined in an examination of daily growth patterns recorded in otolith microstructure (increment width). In Yukon River chum salmon, incremental periodicity appears to vary with freshwater age, or life stage, and ranges from 2 d/increment in alevins to 0.8 d/increment in 50-mm fry. This variability indicates that the circadian rhythm is not entirely genetic, and that environmental influences such as photoperiod, temperature, and feeding regime are probably involved.

Chum salmon emigration through the coastal habitats of the Yukon Delta may be brief and last less than 2 weeks (Martin et al. 1987). This estimate may accurately reflect the amount of time spent by juveniles inside and near the delta front, but does not appear to encompass the period associated with estuarine growth in salmon. No transition between freshwater and estuarine residence was indicated in the otolith microstructure of chum salmon studied on the Yukon Delta (Martin et al. 1987). This transitional check has been used previously to indicate the beginning of estuarine residence (Neilson et al. 1985). In the Yukon Delta, it appears that estuarine growth may not begin in juveniles until they pass through the delta front habitat, away from the river's influences. In this manner, the outer portions of the Yukon Delta and nearshore waters of Norton Sound may be serving as an "offshore estuary" or nursery zone. Spatial and temporal aspects of salmon use of nearshore waters of Norton Sound are not known. Residence in estuaries by juvenile chum salmon has been studied in the Nanaimo, British Columbia, estuary, where estimates range from 0 to 18 days (Healey 1979).

Chinook salmon residence in the Yukon Delta estuary was not studied in 1986 or 1987. Healey (1980) estimated that individual chinooks spent an average of 25 days rearing in the Nanaimo estuary or until they reached a fork length of 70 mm. Chinook salmon may move quickly through the Yukon Delta coastal habitats with only a brief interval spent for seawater acclimation at or near the delta front. Seawater acclimation may require 30–40 hours if similar to that of coho salmon (Kepshire and McNeil 1972). After this, the juveniles may linger offshore of the delta front and nearshore waters of southeastern Norton Sound. Reimers (1973) reported estuarine residence of chinook salmon in the Sixes River estuary in Oregon as 3–4 months. Juvenile chinook may remain in Norton Sound for several months, attaining growth and energy reserves for their more extensive seaward migration.

3.3.6 Delta Food Habits

In both 1985 and 1986, juvenile chum salmon (and pink salmon) were found to have highly specific diets primarily consisting of larval, pupal, and adult dipterans (i.e., mostly Chironomidae). These aquatic midges were most likely produced in the tidal sloughs and distributary channels of the delta emergent zone. Fry were thought to have fed on the midges while they were migrating through sloughs, mudflats, and other low salinity environments during summer periods of high river discharge (aquatic drift), offshore winds (wind-blown swarms), or both.

Thirty-four prey were identified in the stomachs of chum salmon fry collected off the Yukon Delta in 1986. The major prey included adult aquatic insects, larval aquatic insects, adult terrestrial insects, copepods (calanoids, cyclopoids, and harpacticoids), mysids, isopods, cladocerans, and seeds and other plant material. More than 30 of the taxa could be classified as terrestrial drift (insects and arachnids), and by comparison to the chironomids provide a minor source of nutrition to downstream migrants.

Adult chironomids and other drift insects were 80–90% of the biomass consumed by chum salmon fry captured on the delta front and delta platform (Wing 1988). Chironomid larvae were also dominant components of their diets (although terrestrial insects were also found) and were especially important in the lower river (Table 3.8). Chironomid larvae and pupae were more important in sloughs than were adults, suggesting

TABLE 3.8—Main foods[1] (Hureau 1969) of Yukon River chum salmon fry, 1986.

Habitat	Stomach sample size	Main foods	
		MF	Species or group
Delta front	172	3,403	Chironomidae
		192	*Eurytemora herdmanni*
		14	*Mysis littoralis*
Delta platform	160	3,665	Chironomidae
		42	*Eurytemora herdmanni*
		18	*Neomysis intermedia*
		16	*Mysis littoralis*
Tidal slough	32	715	Chironomidae
		18	Harpacticoida
Active distributary	177	4,331	Chironomidae
		80	Diptera
		35	Ephemeroptera
		11	Plecoptera
Inactive distributary	296	4,707	Chironomidae
		40	Diptera
		14	Plecoptera
Upper Yukon River[2]	22	5,451	Chironomidae
		23	*Cyclops scutifer*
Andreafsky River[3]	24	3,550	Chironomidae
		434	Ephemeroptera
		20	*Cyclops scutifer*

[1] Main food (MF) = ((% total weight) (100)) ((% total count) (100)).

[2] In river near Pilot Station.

[3] Alaska Department of Fish and Game enumeration site.

that the midges were rearing in this habitat. In aggregate, the aquatic insects (mostly nymphs of Ephemeroptera and Plecoptera) were second in importance to chironomids in river habitats and fourth and fifth in delta platform and delta front areas (Wing 1988). The estuarine copepod *Eurytemora herdmanni* ranked second in importance to chironomids in the delta front and delta platform habitats. Of the mysids, juvenile *Neomysis intermedia* and, to a lesser extent, *Mysis littoralis* were important prey in the offshore portions of the estuary. Wing (1988) suggested that the low proportion of planktonic copepods, cladocerans, mysids, and other estuarine zooplankton in the diets of fry may be indicative of low planktonic production in the coastal habitats sampled. This would force the fry to remain dependent on the aquatic drift at the water surface throughout the period they are present within these habitats.

3.3.7 Salmon Management Concerns

Conservative management of the Yukon River salmon stocks is made difficult by the gauntlet of fisheries through which the fish must pass. Current ADFG management techniques include net mesh size restrictions, time and area restrictions based on inseason escapement indicators, and seasonal closures. Whitmore et al. (1987: 2) characterized the problem as follows:

> Management is made difficult by the character of salmon runs, the nature of the various fisheries, and the river itself. Since most of the fisheries have developed or expanded in recent years, there is a lack of adequate escapement and return data on which to fully evaluate the effects of increased commercial harvest. The various Alaska fisheries, which are scattered over 1,400 river miles, harvest mixed stocks usually several weeks and hundreds of miles from their spawning grounds. Because the Yukon River commercial fisheries harvest mixed stocks, some tributary populations may be under- or overharvested in relation to their actual abundance. For example, in a mixed-stock fishery, where it is impossible to manage each stock separately, some small spawning populations may be reduced to very low levels or even eliminated.

Almost all of the summer-run chum stocks are believed to spawn in Alaska. This is not so for fall-run chum and chinook. Because spawning and fisheries for fall chum and chinook occur on both sides of the border, these species are of primary concern in ongoing U.S.–Canada treaty negotiations. Depending on their origins, these salmon are subjected to varying levels of exploitation along the Yukon drainage. It has been estimated that as much as 40% of the Alaskan harvest of chinook salmon is of Canadian origin (Merritt 1987; Regnart 1987).

Declining stocks of Yukon River fall chum salmon have been a management concern. Stock assessment research by the ADFG indicated that these fish were overexploited during the 1982 through 1984 fishing seasons. Since then the Alaska Board of Fisheries has reduced harvest rates by as much as 50%, and in 1987 the Alaskan fishery for fall chum salmon was closed by emergency order. Canadian officials did not take similar conservation measures and Canadian fishermen reported record catches that year—40,000 commercial and 4,500 subsistence (Whitmore et al. 1987). Area closures were required to protect stocks in 1988.

3.3.8 Ongoing Salmon Research

It is clear that additional research is needed for improved in-season escapement estimates and stock determinations for management purposes. Ongoing and planned research efforts of the ADFG and USFWS are tackling these difficult problems. Current projects were summarized by Whitmore et al. (1987) and include (1) chinook and fall chum stock separation studies (scale patterns and electrophoretic studies); (2) side-scan sonar and tower counting escapement indices for the Anvik, Andreafsky, and Sheenjek rivers; and (3) a main river sonar study near Pilot Station to obtain estimates of total Yukon River salmon abundance.

3.3.9 Other Fish

Pacific salmon are not the only fish taken for commercial purposes in the Yukon Delta. Whitefish, sheefish, and blackfish are commercially harvested and contribute to subsistence fisheries throughout the Yukon drainage (Geiger et al. 1983). Marine species utilized by coastal residents include the saffron cod and possibly the Arctic flounder. Both were shown to be abundant off the Yukon Delta in offshore resource surveys conducted in Norton Sound by the National Marine Fisheries Service (Wolotira et al. 1979).

Wolfe's (1981) summary of the seasonal round of fishing activities for major species in the lower Yukon River in 1981 is shown in Figure 3.7. From 88 households interviewed, he estimated the mean household harvest rates of salmon and other fish by lower Yukon River community for the period June 1980 to May 1981 (Table 3.9). In general, species use varied by community, but in all instances salmon were of greatest numerical importance. Ciscoes, whitefish, sheefish, and blackfish composed the bulk of the remaining subsistence species. The total average commercial harvests of fish (salmon, and in the case of Stebbins, salmon and herring) for the survey period were greater in most communities. These estimates (Table 3.9) are not indicative of the average annual

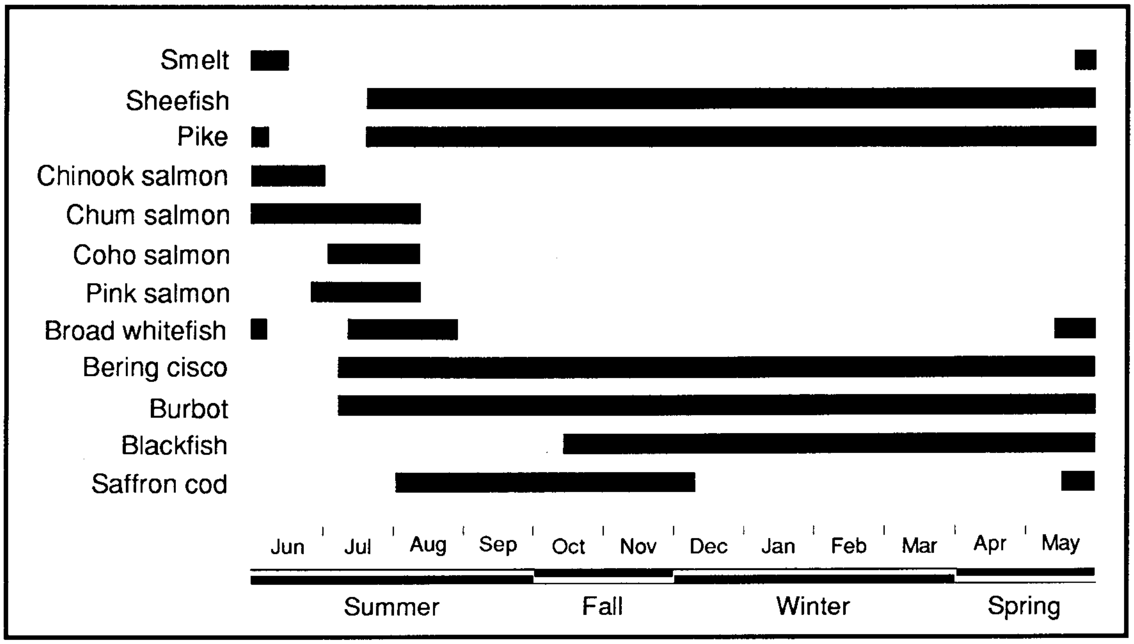

FIGURE 3.7—Seasonal round of fishing activities for major species in the lower Yukon River, 1981. (Adapted from Wolfe 1981.)

harvest conditions that exist in the delta villages. Resource availability and seasonal usage patterns undoubtedly vary widely each year. They do serve as a general indicator of the overwhelming importance of fish in lower Yukon River lifestyles.

During 1984–86 an extensive body of data was obtained by OCSEAP surveys on fish distribution, abundance, and food habits for species other than Pacific salmon. Winter surveys were conducted in December 1984. The 1985 surveys were comprehensive in breadth of species and Yukon Delta coverage. The 1986 surveys were limited by geographic area and species coverage, and focused primarily on salmon outmigration and residency. In that year, whitefish, ciscoes, and sheefish were the only other species examined in any detail regarding their distribution and abundance in coastal habitats. Martin et al. (1986, 1987) have provided detailed accounts of all of these surveys.

During December 1984 a brief under-ice gillnet survey was conducted to document the winter occurrence of major subsistence species of other salmonids (sheefish, whitefish, and ciscoes) and nonsalmonids in selected lower river habitats (Table 3.10). Nine species were captured, of which the anadromous forms (sheefish, whitefish, and smelt) were most abundant.

TABLE 3.9—Mean household subsistence and commercial harvest (dressed weight in pounds) of salmonid and nonsalmonid fish by lower Yukon River community, June 1980–May 1981 (Wolfe 1981).

Community	Average subsistence harvest of fish (lb.)	Average commercial harvest of fish (lb.)	Fish portion of total fish and wildlife harvest: Total harvest %	lb.	Subsistence harvest %	lb.
Alakanuk	3,155	7,244	86	12,065	65	4,821
Emmonak	1,983	7,784	92	10,543	70	2,759
Kotlik	1,983	22,637	95	26,066	58	3,429
Mountain Village	3,498	19,255	95	20,176	79	4,419
Sheldon Point	7,633	17,306	89	19,457	78	9,784
Stebbins	3,918	2,196	71	8,571	62	6,375

TABLE 3.10—Summary of gill net catch in the Yukon Delta during December 1984 (Martin et al. 1986).

Habitat and station	Effort (hours)	Catch by species*									Total catch
		SHE	HBW	BRW	BRC	LSC	BSM	PIK	BUR	FHS	
Major active distributary											
Nunaktuk Island	24.00	11	—	—	5	—	—	—	—	—	16
Okwega Pass	22.42	1	2	1	—	—	—	—	3	—	7
Kwikpuk, Kwikpuk Pass	25.92	—	1	—	—	—	—	1	2	—	4
Near Akularak Pass	20.58	—	—	—	—	4	—	—	2	—	6
Minor active distributary											
Caseys Channel	23.25	1	—	—	—	—	—	—	—	—	1
Bugomowik Slough	24.00	—	—	—	—	—	—	—	—	—	0
Elongozhik Slough	22.00	—	—	—	—	—	9	—	—	1	10
Okshokwewhik Pass	22.83	1	3	—	—	—	—	—	1	—	5
Black River	21.42	9	—	—	2	1	16	1	1	—	30
Minor inactive distributary											
Kuemeluk–Kanelik Junction	20.83	4	—	1	1	—	—	—	—	—	6
		27	6	2	8	5	25	2	9	1	85

*SHE = sheefish, HBW = humpback whitefish, BRW = broad whitefish, BRC = Bering cisco, LSC = least cisco, BSM = boreal smelt, PIK = northern pike, BUR = burbot, FHS = fourhorn sculpin.

Freshwater species (northern pike and burbot) were also captured, but in lesser numbers. Only one marine species (fourhorn sculpin) was captured in the winter surveys. Little can be speculated about the use of habitats by these species due to the small catches and limited areas sampled. Martin et al. (1986) observed that (1) sheefish, Bering cisco, least cisco, northern pike, and burbot were captured at brackish and freshwater sites; (2) boreal smelt and fourhorn sculpin were captured only in brackish waters; and (3) humpback and broad whitefish were captured only in fresh water. Most fish were large, suggesting their possible use of the coastal delta habitats, at least in early winter.

Summer surveys were conducted over 97 days of sampling in the Yukon Delta habitats from mid-June to mid-September 1985. Thirty-two species of fish, including 13 anadromous, 9 freshwater, and 10 marine species, were identified (Table 3.11). Fishing effort was distributed throughout the study area, with 43% of the effort in coastal, 35% in river, and 22% in lake habitats. More than 44,000 fish were captured. Whitefish were most abundant and accounted for 35% of the catch. The catches of round whitefish and trout-perch in coastal habitats along the margin of the delta represent documented range extensions for both species in this region. Juvenile salmon contributed only 3% to the total catch. Table 3.12 lists the dominant species compositions within the major habitats. Dominant species are defined here as species that represented more than 5% of the total catch within a specified habitat. Estuarine forms are discussed.

Sheefish, whitefish, and ciscoes accounted for more than 65% of the total 1985 catch. Juveniles of all three groups passed through the active distributaries during their downstream migration, moved into and out of lakes adjacent to the river, and were most abundant in coastal mudflats and sloughs. These habitats appear to be of primary importance to these species for rearing. Kendel et al. (1975) characterized the seasonal movements of the mature segments of Mackenzie River anadromous populations as an upstream migration of adults into river systems before spawning, followed by a postspawning migration to coastal waters. Fry spend variable amounts of time in river systems before moving down to delta and coastal waters. Baxter (unpubl. manuscr. cited by Martin et al. 1986) described seasonal movements of resident whitefish (broad and humpback) from the Kuskokwim River: summer—most whitefish are found in shallow tundra lakes and associated sloughs; August—outmigration from tundra habitat begins; September—adult males join mature females in the main river (spawning is initiated after water temperatures drop below 0°C); late September to freeze-up—nonspawning fish (adults spawn every other year) move from tundra habitats into the main river below the spawning area;

October—immatures leave tundra habitats and mill with nonspawning adults. In the Yukon Delta during 1985, juveniles moved into the slough and mudflat areas (low salinity, 3 ppt) in mid-June, remaining there at least through September. Only juvenile ciscoes moved farther offshore into waters of greater salinities, e.g., 20 ppt at the delta front. Barton (1983) reported similar information on the timing of movements of immature fish in the lower Yukon River. Winter icing of summering areas was expected to force the small fish into the lake and channel overwintering habitats in the delta.

In 1986 the peak outmigration of coregonid fish occurred in July, which was a little later in summer than was noted for these species in 1985 (Martin et al. 1987). Juvenile ciscoes reportedly were three times more abundant than juvenile sheefish and whitefish. Intertidal mudflat and tidal slough habitats were, as in 1985, the habitats most heavily utilized by these species.

Arctic flounder were relatively abundant over the inner delta platform, coastal mudflats, and tidal slough portions of the study area in 1985 (Martin et al. 1986). They were also present in the habitats extending offshore but were not readily captured in the pelagic-sampling survey gear. They were often captured with starry flounder, especially in mudflat habitats, which may reflect a similarity in feeding habits. The information collected on size of fish suggests that the coastal Yukon Delta provides important nursery habitat for this species, at least during the summer.

Saffron cod have been estimated to represent about 50% of the total demersal fish biomass of Norton Sound. Greatest abundances have been reported near Port Clarence–Grantley Harbor and in Golovnin Bay (Wolotira et al. 1979; Zimmerman 1982). During summer they were frequent inhabitants of all nearshore waters in Norton Sound but were only captured in the coastal Yukon Delta habitats during the August and September periods of the 1985 survey. Larger saffron cod were able to move much nearer to the coast into the freshwater habitats than were the younger cod, which remained in brackish waters of the delta front where salinities reached 16 ppt (Martin et al. 1986).

Boreal smelt were relatively abundant in all coastal habitats but were most frequently captured in the delta front. Martin et al. (1986) reported that while the size of the smelt captured varied with time and season, the fish tended to be small. This size composition had previously been noted in summer catches in nearshore waters of Norton Sound (Barton 1977) and the Chukchi Sea (Haldorson and Craig 1984). Considering maturity relationships reported by the latter authors, Martin et al. (1986) reported that most delta fish captured were immature and probably between 4 and 5 years old. The boreal smelt is a freshwater-spawning fish whose eggs and larvae are transported downstream to estuarine nurseries.

Pond smelt are generally considered to be a freshwater species that occasionally occupies estuarine waters. In early summer of 1985, pond smelt were reported in small numbers in coastal sloughs, with the largest catches occurring in August and September in the delta front; given the large size and mature condition of fish sampled in this habitat during June, the coastal sloughs may occasionally be used for spawning by pond smelt (Martin et al. 1986).

TABLE 3.11—List of fish of the Yukon Delta.

Common name	Scientific name
Anadromous	
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Pink salmon	*Oncorhynchus gorbuscha*
Dolly Varden/Arctic char	*Salvelinus malma/S. alpinus*
Sheefish	*Stenodus leucichthys*
Arctic cisco	*Coregonus autumnalis*
Bering cisco	*Coregonus laurettae*
Least cisco	*Coregonus sardinella*
Boreal smelt	*Osmerus eperlanus*
Threespine stickleback	*Gasterosteus aculeatus*
Ninespine stickleback	*Pungitius pungitius*
Arctic lamprey	*Lampetra japonica*
Freshwater	
Humpback whitefish	*Coregonus pidschian*
Broad whitefish	*Coregonus nasus*
Round whitefish	*Prosopium cylindraceum*
Pond smelt	*Hypomesus olidus*
Longnose sucker	*Catostomus catostomus*
Northern pike	*Esox lucius*
Burbot	*Lota lota*
Alaska blackfish	*Dallia pectoralis*
Trout-perch	*Percopsis omiscomaycus*
Marine	
Starry flounder	*Platichthys stellatus*
Arctic flounder	*Liopsetta glacialis*
Saffron cod	*Eleginus gracilis*
Arctic cod	*Boreogadus saida*
Fourhorn sculpin	*Myoxocephalus quadricornis*
Pacific herring	*Clupea harengus pallasi*
Capelin	*Mallotus villosus*
Bering poacher	*Occella dodecaedron*
Pricklebacks	*Lumpenus* spp.
Whitespotted greenling	*Hexagrammos stelleri*

TABLE 3.12—Relative abundance of dominant fish in Yukon Delta habitats in 1985 (Martin et al. 1986).

	Total number of—		Dominant fish	
Habitat	Species	Fish caught	Species	% catch
COASTAL				
Delta front	17	4,715	Boreal smelt	63
			Saffron cod	12
			Pond smelt	8
			Ninespine stickleback	8
			Pacific herring	5
Inner delta platform	16	1,761	Arctic flounder	33
			Boreal smelt	19
			Sheefish	8
			Chum salmon	7
			Fourhorn sculpin	5
Mudflats	19	14,404	Unidentified whitefish	69
			Sheefish	9
			Unidentified cisco	8
Tidal slough	22	9,552	Unidentified whitefish and cisco	50
			Ninespine stickleback	20
			Humpback whitefish	6
			Arctic flounder	5
			Saffron cod	5
RIVER				
Interisland channel	1	2	Unidentified whitefish	100
Major active distributary	18	2,291	Unidentified whitefish and cisco	37
			Sheefish	13
			Chum salmon	13
			Boreal smelt	12
			Ninespine stickleback	8
Minor active distributary	21	6,340	Unidentified whitefish and cisco	35
			Unidentified smelt	26
			Burbot	15
			Chum salmon	6
Major inactive distributary	7	87	Least cisco	36
			Humpback whitefish	23
			Sheefish	15
			Broad whitefish	14
Minor inactive distributary	8	95	Humpback whitefish	38
			Least cisco	38
			Broad whitefish	6
			Northern pike	10
LAKE/POND				
Connected lake	8	159	Sheefish	32
			Unidentified whitefish and cisco	31
			Northern pike	19
			Blackfish	6
			Burbot	5
Lake outlet channel	11	5,216	Unidentified whitefish and cisco	75
			Sheefish	12
Landlocked lake	1	1	Blackfish	100

Ninespine stickleback were present in all coastal habitats sampled in the 1985 surveys. They were most abundant in the tidal sloughs but were also commonly found in the delta front. Their occurrence was noted in all delta waters with salinities to nearly 20 ppt.

Burbot were caught in nearly as many habitats as the ninespine stickleback, but never in marine or brackish waters. In the latter part of June most burbot captured in coastal sloughs were small; larger fish were reported in minor active distributaries. As the season progressed, almost all burbot sampled were found in minor active distributary waters, including a larger number of smaller fish than had been reported in June.

The OCSEAP research represented the first food habits study of fish from this part of Alaska. The general trend in fish prey resource utilization by opportunistic foragers across the delta was characterized as (1) drift and epibenthic aquatic insects in distributary habitats; (2) epibenthic organisms (copepods, mysids, and amphipods) in coastal slough, mudflat, and inner platform habitats; and (3) planktonic copepods in the delta front habitats (Table 3.13).

TABLE 3.13—Diets (percentage of total index of relative importance for prey taxon) of Yukon Delta salmonid and nonsalmonid fish, 1985 (Martin et al. 1986).

Fish species, main habitats,[1] and sample size	Prey taxon							
	Calanoida	Harpacticoida	Cyclopoida	Mysidacea	Isopoda	Amphipoda	Diptera	Other[2]
Bering cisco DF, C, R, L N = 19	74.5	0.1	—	23.6	—	1.8	—	—
Least cisco DF, C, R, L N = 65	36.7	38.0	4.7	2.6	—	7.3	8.3	2.4
Humpback whitefish C, R, L N = 68	10.4	31.0	8.4	1.0	—	42.7	3.1	3.4
Pink salmon C N = 26	17.7	0.9	13.0	—	—	—	63.3	5.1
Chum salmon RA, C, DF N = 69	2.1	0.2	5.4	—	0.3	—	89.1	2.9
Coho salmon C, RI N = 4	1.7	—	—	—	27.4	—	—	70.9
Chinook salmon RA N = 6	—	—	—	—	88.1	—	3.1	8.8
Sheefish C, R, L N = 66	2.0	—	3.5	70.7	—	14.2	7.6	2.0
Pond smelt DF, C N = 34	89.0	4.6	1.3	0.8	—	2.6	0.3	1.4
Boreal smelt DF N = 48	51.0	0.1	6.6	26.1	—	0.3	—	15.9
Burbot C, RI N = 25	1.3	—	—	65.4	0.2	0.4	11.1	21.6

[1] DF = delta front, C = coastal, R = river, RA = active distributary, RI = inactive distributary, L = lake.

[2] Includes other crustaceans, insects, fish, and plant materials.

Epibenthic sampling was attempted in the fishery surveys of coastal habitats in 1985, but was unsuccessful because of gear deployment difficulties on muddy substrates. Research objectives to describe food availability in the various delta habitats were therefore not realized. As noted by Martin et al. (1986), it is difficult to relate dependency of a species to a particular habitat by apparent food habits, without data on total amounts of food available. The authors did, however, identify a restricted number of "requisite" groups that occurred prominently in the diets of more fish during their residencies or migrations within the delta.

Several species appeared to be more specialized feeders in the Yukon Delta. Boreal smelt and sheefish relied almost exclusively on epibenthic mysids for food in the habitats sampled. Pink salmon were similarly noted to be feeding only on aquatic insect larvae everywhere except the delta front (Martin et al. 1986).

3.4 YUKON DELTA AVIFAUNA

The importance of the Yukon–Kuskokwim Delta to waterfowl populations is well known. It is one of the largest areas of productive breeding habitat for waterfowl and cranes in North America. Because of the breeding and nesting habitat provided by the Yukon–Kuskokwim Delta to species that have exhibited significant population declines in recent years (cackling Canada geese, Pacific white-fronted geese, emperor geese, black brant, and pintail), its importance to the waterfowl of North America appears even greater.

In addition to waterfowl, the Yukon Delta and associated nearshore waters provide habitat for breeding and migrating populations of shorebirds, gulls, cranes, and seabirds. The Yukon–Kuskokwim Delta is used by more species, in greater numbers, and higher densities than any other littoral area of the eastern Bering Sea (Gill and Handel 1981).

Birds comprise an important subsistence resource for the people of the Yukon–Kuskokwim Delta. Geese, a traditional resource, are especially important. Declining populations of geese have forced managers to reduce subsistence harvests of geese during their breeding season. Large numbers of ducks, sandhill cranes, swans, and ptarmigan are also valuable components in the subsistence food base (Wolfe 1981).

The principal species of birds occurring in the Yukon Delta and their seasonal use of the major habitats are presented in Table 3.14. This table is adapted from Truett (1985) and includes additional information from the USFWS. An evaluation of the "high" use habitats, ranking use by total number of species, reveals that the grass/sedge meadows–tidal meadows (salt meadows and marshes) exhibit greatest use (38 species), followed by distributary channels and sloughs (19 species), grass/shrub (upland) transition (17 species), unvegetated coastal mudflats (17 species), and nearshore delta platform and delta front waters (10 species). These utilization patterns are shown in Figure 3.8. There is an apparent increase in diversity of avifauna proceeding from marine waters to salt meadows, followed by a decrease in species diversity observed across delta habitats to the uplands (Table 3.15).

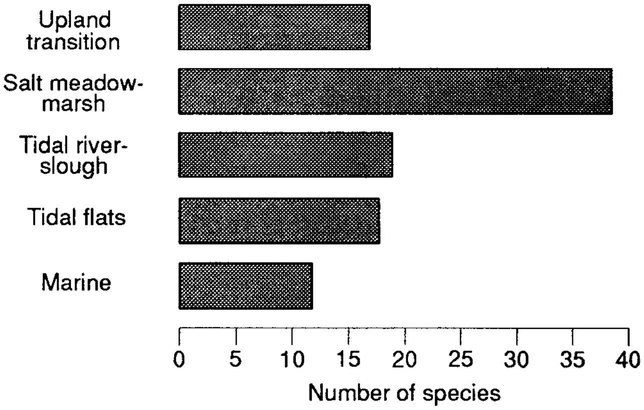

FIGURE 3.8—Avifaunal use of Yukon Delta habitats.

Although information on the phenologies of the numerous species occurring on the delta varies, most make only a limited temporal use of the Yukon Delta. The greatest period of use occurs between May and September. This timing corresponds with the breeding season for most shorebirds and waterfowl occupying coastal habitats each year.

3.4.1 Swans and Geese

The major species occurring in the Yukon Delta include the tundra swan, cackling Canada goose, white-fronted goose, Taverner's Canada goose, emperor goose, snow goose, and black brant. All except the snow goose nest on the delta tundra. The relative importance of the Yukon Delta as goose nesting habitat, on a regional basis, appears to be less than one would expect. The highest densities of nesting geese are found south of the Black River near Hazen Bay. Good data describing the nesting densities of geese on the Yukon Delta are not presently available; however, existing information indicates a reduced use of the tundra habitat by geese (Eldridge 1987).

The tundra swan, Taverner's Canada goose, emperor goose, and black brant are the most common nesters on the Yukon Delta. The white-fronted goose and the cackling goose nest in greater numbers farther south

TABLE 3.14—Habitat use by birds of the Yukon Delta. (Adapted from Truett 1985.)

		Percent of reference population				Use of major habitats[3]						
Species[1]	Population of area[2]	Yukon Delta	Alaska	Pacific Flyway	North America	Delta platform and delta front	Coastal mudflats	Distributary channels and sloughs	Grass/sedge meadows and tidal meadows	Grass/shrub transition	Nature of use[4]	Period of use
Red-throated loon	f 1,000s	30	10	—	—	M	N	H	H	M	B	May–Sep
Arctic loon	f 10,000s	30	10	—	—	L	N	M	H	H	B	″
Pelagic cormorant	f 100s	30	t	t	t	H	N	N	N	N	B	″
Tundra swan	s 1,000s	20	10	10	10	N	N	L	H	H	B	″
White-fronted goose	s 10,000s	30	10	20	10	N	N	H	H	H	B	″
Snow goose	s 10,000s	30	20	10	10	N	N	N	M	H	M	May & Sep
Black brandt	s 10,000s	50	50	50	50	L	M	H	H	L	M, B	May–Sep
Cackling Canada goose	f 1,000s	20	20	20	20	L	M	H	H	H	B	″
Taverner's Canada goose	s 10,000s	30	30	30	30	L	L	H	H	H	B	″
Emperor goose	s 10,000s	40	40	40	40	L	M	H	H	H	B	″
Green-winged teal	s 10,000s	30	10	—	—	N	L	M	H	H	B	″
Mallard	s 1,000s	30	10	—	—	N	L	L	H	H	B	″
Pintail	f 100,000s	40	10	—	—	L	H	H	H	M	B, P	″
Northern shoveler	f 10,000s	40	10	—	—	N	L	L	H	M	B, P	″
American widgeon	s 1,000s	30	10	—	—	N	L	L	H	M	B, P	″
Greater scaup	s 10,000s	20	10	—	—	L	N	L	M	H	B	″
Common eider	f 10,000s	50	10	10	—	H	L	H	H	L	BM	″
King eider	? 10,000s	50	10	10	—	H	N	N	N	N	M	Apr–May
Spectacled eider	f 10,000s	50	50	50	50	H	L	M	H	L	B	Apr–Sep
Steller's eider	f 1,000s	50	10	10	10	H	N	H	H	N	B, P	″
Oldsquaw	f 100,000s	30	10	—	—	L	L	M	H	H	B	Apr–Oct
Black scoter	f 10,000s	30	20	—	—	M	N	H	H	M	B, P	″
Surf scoter	f 10,000s	50	10	—	—	H	N	N	N	?	M, P	″
White-winged scoter	f 1,000s	20	10	—	—	H	N	N	N	?	M, P	″
Sandhill crane	f 10,000s	30	10	—	—	N	N	N	H	N	B, P	May–Sep
Black-bellied plover	s 10,000s	30	—	—	—	N	M	N	M	H	B	″
American golden plover	f 10,000s	30	—	—	—	N	H	H	H	M	B, P	″
Whimbrel	f 1,000s	50	—	—	—	N	H	H	H	N	P	Jun–Aug
Bristle-thighed curlew	f 1,000s	40	40	40	40	N	L	L	H	N	P	″
Hudsonian godwit	f 1,000s	60	30	—	—	N	H	N	H	N	P	Jul–Aug
Bar-tailed godwit	f 10,000s	50	50	—	40	N	H	N	H	H	B, P	May–Sep
Ruddy turnstone	f 1,000s	30	—	—	—	N	M	M	M	M	B, P	″
Black turnstone	s 10,000s	40	30	—	—	N	H	H	H	L	B, P	″
Red knot	f 10,000s	40	—	—	—	N	H	N	N	N	P	Jun–Sep
Semipalmated sandpiper	f 1,000s	40	—	—	—	N	H	H	H	N	P	″
Western sandpiper	s 100,000s	40	40	—	—	N	H	H	H	H	B, P	May–Sep
Sharp-tailed sandpiper	s 1,000s	40	—	—	—	N	H	H	H	N	P	Aug–Sep
Rock sandpiper	s 10,000s	40	—	—	—	N	H	M	M	M	B, P	May–Sep
Dunlin	s 100,000s	40	—	—	—	N	H	H	H	L	B, P	″
Long-billed dowitcher	s 1,000s	40	—	—	—	—	H	H	H	L	P	Jul–Sep
Red-necked phalarope	s 100,000s	30	—	—	—	H	M	M	H	M	B	May–Sep
Red phalarope	s 10,000s	50	—	—	—	H	M	M	H	L	B	″
Parasitic jaeger	f 1,000s	30	—	—	—	L	H	L	H	H	B	May–Aug
Long-tailed jaeger	s 1,000s	30	—	—	—	L	H	L	H	H	B	″
Mew gull	s 1,000s	30	—	—	—	L	H	M	H	H	B	May–Sep
Glaucous gull	s 1,000s	40	—	—	—	M	H	H	H	M	B	″
Black-legged kittiwake	s 100s	50	—	—	—	H	N	N	N	N	B?	″
Sabine's gull	s 1,000s	50	—	—	—	L	L	M	H	M	B	May–Aug
Arctic tern	s 1,000s	40	—	—	—	M	L	M	H	M	B	″

[1] Species include only common birds of wetland habitats that may be adversely affected by petroleum development.

[2] f = few, s = several.

[3] Relative levels of use: L = low, M = medium, H = high, N = not used.

[4] B = breeding, M = migrant, P = postbreeding.

TABLE 3.15—Mean numbers of birds per kilometer of transect by season and habitat, 1986 (Eldridge 1987).

	Spring[1]			Summer[2]			Fall[3]			Total[4]	
	Mudflat	Ocean	Tundra	Mudflat	Ocean	Tundra	Mudflat	Ocean	Tundra	Birds /km	Number observed
Loons											
Pacific loon	0	tr	0.11	0.04	tr	0.34	0.18	0.02	0.28	0.09	469
Red-throated loon	0	0.01	0.06	0	tr	0.05	0	tr	0.02	0.01	71
Total	0	0.02	0.18	0.04	0.01	0.39	0.18	0.03	0.30	0.11	550
Grebes											
Red-necked grebe	0	0	0.01	0	0	0	0	0	0	tr	8
Unidentified	0	0	0	0	0	tr	0	0	tr	tr	2
Total	0	0	0.01	0	0	tr	0	0	tr	tr	10
Tundra swan	2.96	0.1	1.32	2.81	tr	0.73	14.18	0	1.39	0.47	2,423
Geese											
Emperor goose	0	0	0.01	0	0	0.03	0	0	0.15	0.03	129
Canada goose (incl. Taverner's)	0.16	0	0.42	6.69	0	0.52	3.03	0.03	0.67	0.24	1,217
White-fronted goose	0.16	0	0.09	0.27	0	0.04	0.71	0	0.17	0.04	207
Black brandt	4.32	0.03	0.01	0	0	0	0	0.01	0	0.02	91
Snow goose	0	0	1.05	0	0	0	0	0.04	0.94	0.23	1,187
Total	4.64	0.03	1.60	6.96	0	0.59	3.75	0.09	1.92	0.55	2,831
Dabbling ducks											
Pintail	3.04	0.02	1.57	29.37	0.14	1.10	206.21	0.05	3.25	2.01	10,301
American widgeon	0	0	0.07	1.12	0	0.01	1.69	0	0.78	0.13	685
Northern shoveler	0.24	0	0.11	0	0	0.10	6.07	0	0.07	0.06	323
Green-winged teal	0.40	0	0.02	0	0	0.12	2.07	tr	1.84	0.30	1,512
Gadwall	0	0	0	0	0	tr	0	0	0	tr	3
Mallard	0	0	0.14	0.09	0	0.04	7.29	0	0.46	0.12	624
Unidentified	0	0	0.04	0	0	0	79.75	0.07	0.97	0.60	3,091
Total	3.68	0.02	1.96	30.58	0.14	1.37	303.07	0.11	7.37	3.23	16,543
Diving ducks											
Greater scaup	0	0.01	0.35	1.92	tr	0.26	0	0	0.26	0.10	507
King eider	0	0.04	0.01	0	0	0	0	0	0	0.01	32
Common eider	0	0.64	0.02	0	0	0	0	0	0	0.09	438
Spectacled eider	0	0	0	0	tr	0	0	tr	0.01	tr	18
Unidentified eider	0	tr	0	0	0	tr	0	0	0	tr	3
Black scoter	0	tr	0.08	0	0.25	0.06	0	0.22	0.04	0.14	732
Surf scoter	0	0.01	0.01	0	0	0	0	0.01	0	tr	28
Unidentified scoter	0	tr	0.02	0	0.13	tr	0	0.13	0.01	0.07	378

TABLE 3.15—*Continued.*

	Spring[1]			Summer[2]			Fall[3]			Total[4]	
	Mudflat	Ocean	Tundra	Mudflat	Ocean	Tundra	Mudflat	Ocean	Tundra	Birds /km	Number observed
Diving ducks (continued)											
Red-breasted merganser	0	0	tr	0	0	0	0	tr	0.04	—	—
Oldsquaw	0	0.38	0.01	0	tr	0.01	0	tr	tr	0.05	266
Canvasback	0.16	0	0.01	0	0	tr	0	0	0	tr	7
Unidentified	0	0.01	0.01	0	0	tr	0	0	tr	tr	15
Total	0	1.10	0.49	1.92	0.38	0.33	0	0.37	0.37	0.48	2,457
Northern harrier	0	0	0	0	0	tr	0	0	0.01	tr	6
Bald eagle	0	0.01	0.01	0	0.01	0	0	0.01	0	tr	1
Sandhill crane	0	0	0.49	0	tr	0.64	0.50	0	0.30	0.15	744
Shorebirds	0	tr	0.87	0.50	0.07	1.84	179.79	0.52	7.30	2.50	12,827
Jaegers	0	0.02	0.06	0	0.01	0.04	0	0	0.02	0.01	68
Gulls											
Glaucous gull	1.04	0.08	0.76	4.15	0.11	0.58	5.71	0.22	0.50	0.35	1,796
Mew gull	0	0	0.02	0.13	0.02	0.06	0	tr	tr	0.01	67
Sabine's gull	0	tr	0.04	0	0	0.07	0	0	0	0.01	51
Herring gull	0	0	0	0	0	0	0	tr	0	tr	4
Kittiwakes	0	0	tr	0	0.01	0	0	0.01	0	tr	33
Total	1.2	0.10	0.90	4.46	0.14	0.92	5.96	0.24	0.52	0.41	2,123
Terns	0.16	0.01	0.08	0.08	0.01	0.21	0.25	0	0.01	0.03	174
Seabirds											
Black-legged guillemot	0	0	0	0	tr	0	0	0	0	tr	3
Murres	0	0.01	0	0	tr	0	0	tr	0	tr	11
Unidentified seabird	0	tr	0	0	tr	0	0	0	0	tr	19
Unidentified procellarid	0	tr	0	0	0.02	0	0	tr	0	tr	14
Cormorants	0	tr	0	0	tr	0	0	tr	0	tr	4
Total	0	0.01	0	0	tr	0	0	0.03	0	0.01	51
Unidentified owls	0	0	0	0	0	tr	0	0	tr	tr	3
Short-eared owl	0	0	0	0	0	tr	0.04	0	tr	tr	5
Total linear transect (km)	12.5	672.1	390.3	22.4	1,075.1	490.2	28.1	1,683.2	750.2		

[1] Spring includes surveys from 22 April to 4 June.

[2] Summer includes surveys from 18 June to 2 August.

[3] Fall includes surveys from 15 August to 17 October.

[4] Totals are based on all birds observed over all surveys.

on the Yukon–Kuskokwim Delta. Tundra swans nest throughout the Yukon Delta, with highest use near the coast in tidal meadows on raised tundra hummocks (King and Dau 1981). They also make use of lakes, ponds, tidal rivers, and sloughs (Truett 1985). Most notably, 83% of the tundra swans observed over the entire Yukon–Kuskokwim Delta in 1985 were on Yukon Delta mudflats in fall (Ernst 1986). A similar trend in seasonal habitat use and relative abundance of swans was reported by Eldridge (1987).

Three species of geese nest within the shrub zone, outside of tidal influence: cackling goose, white-fronted goose, and Taverner's Canada goose. The emperor goose nests near the coast, while the black brant, the most "marine" of the geese, confines its nesting to salt meadow habitats. More specifically, black brant build their nests in sedge associated with small shallow ponds and scattered elevated patches of sedges on intertidal mudflats (Truett 1985). These areas are highly susceptible to effects of storm surges.

Although the snow goose does not nest in the Yukon Delta, migrants appear in the spring and fall and utilize both inland and coastal meadows for feeding.

The decreasing population levels of cackling Canada geese, Pacific white-fronted geese, emperor geese, and black brant have been linked to low specific reproductive success. Temperature, seasonal storms and floods, and predation are the primary environmental influences thought to be involved. Predators of geese on the delta include Arctic foxes, mink, glaucous gulls, and jaegers. Predation mortalities are greatest for egg and juvenile life stages. Spring waterfowl hunting and egg gathering activities on the delta have also had a role in the decline of the goose populations.

Waterfowl and sandhill cranes position their nests on elevated ground. Such nesting sites become free of snow, ice, and meltwater earliest in spring (Boise 1977). Colder-than-usual springs and summers can depress nesting success by delaying the occupation of nesting areas. Storm surges and spring floods can inundate the tundra nesting areas, or destroy actual nests, or prevent use of potential nesting sites. However, other factors (food, condition, climate) not necessarily associated with the Yukon Delta *per se* may be involved in determining the proportion of geese that attempt to nest in a given year (Petersen 1987).

The Arctic fox is a major predator of waterfowl on the Yukon Delta. In years when foxes are abundant, their predation on nests and young may significantly affect production. The role of fox predation in reducing population productivity has been frequently reported (Ely et al. 1986, 1987; Stehn 1986; Petersen 1987).

Swans and geese feed primarily on macrophytes. Rhizomes, tubers, and young shoots are favored foods. All species make extensive use of the tidal meadows of the Yukon Delta, and nesting locations are often situated near meadows where plant foods are plentiful. Important foods for all geese are present in the intertidal meadows and in the tidal sloughs and ponds. These foods include *Carex ramenskii, C. subspathacea, Triglochin palustris, Puccinellia phryganodes,* and the seeds and leaves of various grasses (Palmer 1976). Immediately following fledging and molt periods in early August, most geese move inland to feed on ripening berries. Crowberries (*Empetrum nigrum*) are an important component of the goose diet in autumn (Palmer 1976).

3.4.2 Ducks

At least 11 species (common, spectacled, and Steller's eiders; oldsquaws; greater scaups; canvasbacks; mallards; American widgeons; northern shovelers; green-winged teal; and red-breasted mergansers) nest in the coastal lowlands of the Yukon Delta, near tundra ponds and lakes throughout the region, and may feed in intertidal mudflats or nearshore water habitats of the delta in considerable numbers. The greater scaup was the most common diving duck observed by Eldridge (1987) in the nearshore waters in 1986.

Although eiders exhibit high use of the delta platform/delta front region, nonbreeding surf scoters are the most numerous diving duck occurring in the nearshore marine waters (Truett 1985). This species feeds extensively on estuarine and marine benthic invertebrates occurring here. It probably originates in nesting areas throughout western and interior Alaska (Truett 1985).

The pintail is the most abundant nesting duck and the most abundant staging species in the Yukon Delta (Jones and Kirchhoff 1978). Total numbers normally occupying the Yukon–Kuskokwim Delta in the summer may approach 1 million (King and Dau 1981). This species feeds extensively on mudflats and tide pools on a variety of vegetation (particularly *Potamogeton filiformis* and *Carex* seeds) and invertebrates (*Saduria entomon, Neomysis intermedia,* amphipods, and polychaetes) (Kirchhoff 1978). Highest use of this habitat occurs in May. By late June and July, the pintails move to the inland tundra to nest and into tidal sloughs and distributaries during the molt. By early August, pintails return to the intertidal zone to feed.

Pintails appear to prefer the area between the north and middle forks of the Yukon River, and the ponded habitat near the Black River (Eldridge 1987). Ernst (1986) also emphasized the importance of this segment of the Yukon Delta during his coastal surveys, noting that pintails along this segment accounted for 75% and

60% of all pintails counted along the entire Yukon coast in 1985 and 1986, respectively.

3.4.3 Shorebirds

The Yukon–Kuskokwim Delta is used by more species of shorebirds, in greater numbers, and higher densities than any other littoral area of the eastern Bering Sea coast (Gill and Handel 1981). Dominant species are black turnstone, western sandpiper, rock sandpiper, dunlin, long-billed dowitcher, bristle-thighed curlew, American golden plover, bar-tailed godwit, whimbrel, red knot and sharp-tailed sandpiper, red-necked phalarope, and red phalarope.

Recent aerial surveys of the Yukon Delta found that the areas most used by shorebirds were the northern portion of the delta (between the middle and north forks of the Yukon River) and the Black River area (Eldridge 1987). The most common shorebirds observed by Jones and Kirchhoff (1978) in this same area were red phalaropes, long-billed dowitchers, and dunlins.

The habitats of particular importance to the shorebirds are the intertidal mudflats and associated *Carex* meadows (Eldridge 1987). The mudflats provide important invertebrate prey for feeding shorebirds, while the meadows provide nesting sites close to these feeding areas.

Shorebird prey include isopods, mysids, amphipods, polychaetes, and larval and adult insects (Jones and Kirchhoff 1978; Gill and Handel 1981). In their study of arctic nesting shorebirds, Gill and Handel (1981) found that food is probably the single most important factor regulating population numbers, timing of breeding, and habitat use.

Insect prey can be of particular importance to shorebirds. Chironomid and other dipteran larvae constitute the dominant food of dunlins (Holmes 1970). Adult dipterans and trichopteran larvae are also eaten. Holmes (1972) found that the hatch of western sandpipers in mid-June occurred at the same time as the first major emergence of adult insects. Young birds fed on adult dipterans and coleopterans, gradually switching to a diet of dipteran larvae. Food supplies seemed to be a major factor limiting populations. Shorebird hatching timed to the emergence of adult dipterans has also been proposed as an ecological adaptation of breeding shorebirds of the Arctic coastal plain (Maclean 1980).

3.4.4 Other Birds

Sandhill cranes are evenly distributed along all coastal portions of the delta, their numbers diminishing only well inland (several kilometers) from the coast. Like geese and swans, they nest in wet coastal tundra on raised ground. They are omnivorous, feeding on plant and animal materials associated with sedge meadows (gastropods, berries, bulbs of *Triglochin palustris,* small fish, voles, and insects such as craneflies and midges) (Truett et al. 1984, citing Boise 1977, 1981).

Arctic and red-throated loons nest throughout the delta, but the red-throated loon is most abundant in coastal areas, nesting in small lakes and feeding on tidal rivers and nearshore waters (Truett 1985). The Arctic loon usually prefers large lakes for nesting and feeding. Both probably prey on fish and on invertebrates, such as tadpole shrimp, fairy shrimp, and caddis fly larvae (Hobbie 1984).

3.4.5 Waterbird Energy Requirements

The Yukon–Kuskokwim Delta encompasses the greatest expanse of wetlands in Alaska and, as such, is one of Alaska's most important wetlands with respect to waterfowl and shorebird production. It is a region where avian food supplies are abundant (Zimmerman 1982). The Yukon Delta represents a minor portion of the Yukon–Kuskokwim complex available to migratory birds, but plays a vital role in the population ecology of many species. As an example, nearly one-quarter of the Alaskan northern pintail population, or 1 million birds, are distributed over Yukon–Kuskokwim habitats between May and September each year. Large flocks of pintails, which may total upwards of 675,000 birds, move onto the Yukon Delta in the fall for premigration energy acquisitions (Ernst 1986; Eldridge 1987).

Estimates of the amount of bird habitat available in the Yukon–Kuskokwim Delta are possible if spatial uniformity in the distribution of estuarine zones (including tundra, mudflat, and coastal) is assumed across the entire region. In this broad context, "wetland" habitat corresponds to tundra and mudflat areas combined and "coastal" habitat corresponds to nearshore waters. The spatial dimensions of delta "habitat types" have previously been reported for the Yukon–Kuskokwim region (King and Dau 1981). In the case of the Yukon Delta, these dimensions were derived from environmental information presented by Eldridge (1987). In this fashion it was determined that the Yukon Delta estuary (8,250 km^2) was composed of 1,980 km^2 of tundra, 720 km^2 of mudflat, and 5,550 km^2 of coastal habitats along 180 km of coastline. This represents less than 5% of similar estuarine habitat (180,000 km^2) on the entire Yukon–Kuskokwim Delta.

Forty-six species of waterbirds were consistently observed on the Yukon Delta in 1986 (Eldridge 1987). Table 3.16 summarizes population and seasonal composition information for prominent waterbirds

TABLE 3.16—Relative abundance and taxonomic composition of Yukon Delta waterbirds in spring, summer, and fall. (Data extracted from Eldridge 1987.)

Bird group	Estimated Yukon Delta population	Dominant species	Dominant species by habitat (% of estimated population)		
			Mudflat	Coastal	Tundra
		Spring (mid-April to early June)			
Loons	510	Pacific loon	—	—	58
		Red-throated loon	—	11	31
Swans	7,092	Tundra swan	40	10	50
Geese	8,965	Black brandt	47	3	—
		Snow goose	—	—	31
		Canada goose	2	—	12
Dabbling ducks	8,930	Pintail	33	2	47
		Green-winged teal	4	—	—
Diving ducks	9,723	Common eider	—	49	—
		Oldsquaw	—	29	—
		Greater scaup	—	—	10
		Canvasback	2	—	—
		Black scoter	—	—	2
Shorebirds	2,297	Red phalarope	24	—	24
		Red-necked phalarope	10	—	10
		Dunlin	8	—	8
Jaegers	324	—	—	51	49
Terns	424	Arctic tern	36	13	51
Gulls	4,276	Glaucous gull	24	14	47
Cranes	1,287	Sandhill crane	—	—	100
Seabirds	55	—	—	100	—
		Summer (mid-June to early August)			
Loons	1,036	Pacific loon	3	—	84
		Red-throated loon	—	—	13
Swans	3,092	Tundra swan	65	—	35
Geese	8,296	Canada goose	78	—	17
Dabbling ducks	34,239	Pintail	83	3	9
		American widgeon	3	—	—
Diving ducks	5,556	Greater scaup	33	—	13
		Black scoter	—	34	—
Shorebirds	5,872	Long-billed dowitcher	22	—	—
		Bar-tailed godwit	8	—	—
		Semipalmated sandpiper	14	—	—
		Dunlin	16	—	—
		Red-necked phalarope	36	—	—
Jaegers	154	—	—	36	64
Gulls	7,801	Glaucous gull	51	11	20
Terns	688	Arctic tern	12	8	80
Cranes	1,683	Sandhill crane	—	—	100

TABLE 3.16—*Continued.*

Bird group	Estimated Yukon Delta population	Dominant species	Dominant species by habitat (% of estimated population)		
			Mudflat	Coastal	Tundra
		Fall (mid-August to mid-October)			
Loons	1,150	Pacific loon	15	14	71
Swans	18,729	Tundra swan	73	—	27
Geese	9,402	Whitefronted goose	7	—	5
		Snow goose	3	—	27
		Canada goose	31	2	19
Dabbling ducks	313,471	Pintail	64	—	3
		Green-winged teal	1	—	2
		Mallard	2	—	—
		Northern shoveler	2	—	—
		American widgeon	—	—	1
Shorebirds	196,373	Golden plover	23	—	—
		Long-billed dowitcher	36	—	—
		Pectoral sandpiper	7	—	—
		Sharp-tailed sandpiper	22	—	—
		Dunlin	10	—	—
Diving ducks	3,750	Greater scaup	—	—	18
		Black scoter	—	44	3
		Unidentified scoter	—	25	5
		Red-breasted merganser	—	—	3
Gulls	8,832	Glaucous gull	63	19	11
Terns	265	Arctic tern	92	—	8
Cranes	1,274	Sandhill crane	38	—	62

occurring on tundra, mudflat, and coastal habitats. More than 43,000 birds were observed on the Yukon Delta in spring (mid-April to early June), more than 68,000 in summer (mid-June to early August), and more than 550,000 during fall (mid-August to mid-October). Information on the total abundance and relative species abundance for shorebirds was abstracted from Eldridge (1987) and Ernst (1986), respectively. This assumes a relative constancy in numerical dominance noted for shorebird species in 1985 and 1986 (it does not affect the bioenergetics calculation described later), and indicates which shorebirds are likely to be outstanding seasonal residents. Population density estimates by season and habitat are provided in Table 3.17; these were computed from transect data of Eldridge (1987).

A conceptual picture portraying the seasonal use of the Yukon Delta by waterbirds can be drawn from the demographic data presented in Tables 3.16 and 3.17. The "seasonal habitat accounts" that follow rely exclusively on 1985 and 1986 data sets and serve to establish the biological framework necessary for discussions of energetics and habitat use. Although large-scale spatial and temporal trends in habitat use have been described, they must be qualified with several reservations: (1) it has been assumed that bimonthly observations reflect habitat use for two-week intervals, (2) daily movement patterns between nesting and foraging habitat could not be established in the 1986 survey data, and (3) important population movements could have gone unobserved in the bimonthly surveys.

Mean weekly spring temperatures of the Yukon Delta range between -6°C (mid-April) and 6.5°C (mid-June). Birds do not begin arriving on the delta in significant numbers until early May. This is a time of steady warming and, as snow and ice melt, increasing habitat availability. By late spring, all estuarine habitats common to the delta are equally available to waterbirds. Ducks, geese, and swans account for the greatest activity on the delta in spring and are distributed across all habitat types. They do, however, exhibit a preference for mudflat and tundra areas. Presumably, these are

TABLE 3.17—Population densities (birds/ha) of the dominant Yukon Delta waterbirds by season and habitat.

Species group	Spring			Summer			Fall		
	Mudflat	Coastal	Tundra	Mudflat	Coastal	Tundra	Mudflat	Coastal	Tundra
Loons	0	0.01	0.23	0.05	0	0.53	0.24	0.03	0.41
Swans	3.94	0.13	1.79	2.79	0	0.55	18.99	0	2.55
Geese	6.10	0.05	1.95	8.99	0	0.71	5.35	0.03	2.42
Dabbling ducks	4.59	0.03	2.12	40.90	0.19	1.56	300.41	1.13	9.50
Diving ducks	0.27	1.37	0.59	2.55	0.34	0.45	0	0.47	0.55
Shorebirds	1.34	0	1.34	7.83	0	0	267.29	0	0
Gulls	1.43	0.11	1.02	5.53	0.16	0.79	7.73	0.30	0.49
Terns	0.21	0.01	0.11	0.12	0.01	0.28	0.34	0	0.01
Cranes	0	0	0.65	0	0	0.85	0.67	0	0.40

important postmigration and prenesting foraging habitats. Snow geese and Canada geese are most common on tundra. Although the tundra environment is important to pintails, they are also abundant on coastal mudflats and shallow intertidal areas. The shallow intertidal is also used in spring by black brants and green-winged teals. The coastal nearshore is almost exclusively used by diving ducks, of which the common eider and oldsquaw are co-dominant species. Greater scaups and canvasback ducks are also common to coastal and mudflat habitats in spring.

Tundra is by far the most heavily frequented Yukon Delta habitat in the spring. Nearly twice as many birds are found over tundra areas and this may reflect initiation of courtship and related breeding activities. Pacific and red-throated loons are present in small numbers over tundra and coastal habitats. Shorebirds and sandhill cranes are found almost exclusively on tundra. Of the shorebirds, red phalaropes, red-necked phalaropes, and dunlin are prominent tundra species. Gulls (primarily glaucous gulls) were moderately abundant over tundra and other delta habitats.

Summer temperatures on the delta normally range between 7.5°C and 11°C. Although some species redistribute themselves across the Yukon Delta, the total abundance of waterfowl changes little from spring levels. In early summer there is a widespread movement among the ducks and geese from coastal to tundra habitats and a greater use of mudflats by pintails and tundra by shorebirds. Semipalmated sandpipers, long-billed dowitchers, and phalaropes account for much of the increased shorebird use and may be represented by late-arriving birds. Dunlins remain numerous; their total abundance in summer remains unchanged from spring levels. Although abundance in the Yukon Delta remains relatively unchanged, the number of diving ducks occurring in coastal waters in summer decreases dramatically (thousands of birds) from spring levels. Large numbers of diving ducks apparently move onto mudflat-foraging and tundra-nesting habitats. Other bird groups (loons, gulls, and terns) experience minor increases in number (hundreds of birds) over the summer.

Fall temperatures on the Yukon Delta tend to decline from a high of 9.5°C (mid-August) to a low of 2°C (early October). A ten-fold increase in waterbird activity occurs on the Yukon Delta in late August. More than one half million birds are distributed on coastal mudflats by September. There is a great influx of northern pintail and tundra swan onto the coastal mudflats in fall. Shorebirds also increase in number. Prominent species of shorebirds include golden plovers, long-billed dowitchers, pectoral sandpipers, and sharp-tailed sandpipers. Diving species remain most abundant in coastal meadows and make little use of mudflat and nearshore water habitats in fall.

How important is the Yukon Delta to regional populations, and what is their role as an exporter of metabolizable energy in fall? These questions are addressed through application of a bioenergetics model (Wiens and Innis 1974) to the seasonal occurrence data for dominant birds of the Yukon Delta (Ernst 1986; Eldridge 1987). The underlying assumption in this application is that the environmental conditions of the Yukon Delta in fall 1985, and throughout the open water season of 1986 are reflective of average annual conditions. The modeling approach, allowing estimation of seasonal energy requirements of delta birds and their energy demands on the delta environment, provides a quantitative means by which relative "habitat" importance can be evaluated at both individual and community levels of organization. This energetics modeling is most limited by the "inventory" character of the existing data; even so, the modeling approach provides an objective measure of deltaic habitat values.

A more sophisticated analysis of Yukon Delta bird energetics than is provided by the Wiens and Innis model is not practical within the context of available information. For many species, life history information is incomplete and habitat requirements are not fully known. Large-scale aerial surveys of the Yukon–Kuskokwim region have provided more information on trends in relative abundance for larger, more visible, species such as the ducks, geese, and swans. Unfortunately, these surveys have usually excluded the coastal Yukon Delta *per se,* an area closest to proposed OCS leasing in Norton Sound. Only one complete season of abundance data has been obtained from the Yukon Delta (Eldridge 1987). Of final note, more detailed species-specific research has focused on the population dynamics and ecology of geese at Hazen Bay. A more precise calculation of delta energy requirements is not feasible because life history information is presently lacking which describes (1) the age, sex, and maturity of delta populations; (2) the seasonal food habits, availability of requisite foods, or the metabolic attributes (e.g., "scope-for-growth") of specific foods; (3) the amount of nesting and/or molting by birds in tundra habitats (and associated energy costs of these activities); and (4) the daily foraging behavior of birds, including movement patterns within deltaic habitats.

Despite these shortcomings, the bioenergetics model computes reasonable estimates of a bird's daily and seasonal energy requirements. The modeling procedure involves (1) estimation of seasonal population use of delta habitats; (2) estimation of individual body weights (in each age class); and (3) the coupling of these data with ambient temperature and various metabolic functions to estimate bioenergetic demands of each age class through time (Wiens and Innis 1974). The degree to which actual bird abundance is determined by survey counts governs the realism of the model's results. Realism is also influenced by the manner in which data were collected, particularly the reliability of taxonomic identifications and adherence to standard methods used in the field to evaluate species abundance. Model results are therefore judged to be accurate within an order of magnitude for the larger, more recognizable species (ducks and geese) and less accurate for others (shorebirds). The model-generated estimates are biased at the community and habitat levels by a lack of statistical confidence in population extrapolations (from transect data) and by assumptions regarding habitat availability on the Yukon Delta. In light of the above, Eldridge (1987) cautioned that "due to variable observability of species and flock sizes over distance, density values are not directly comparable between species, and should be considered as minimum values only."

The initial modeling step involves the calculation of daily existence energy (M_t in kcal/m^2 per day) for each of the dominant Yukon Delta species. According to Wiens and Innis (1974), M_t represents "the energy expended in standard metabolism (subject at complete rest), specific dynamic action (internal productive energy: fat deposition, molt, gonad function, growth, calorigenic effect), and limited locomotor activity (cost of free-living activity)." For nonpasserine birds, M_t is described by a linear relation between body size (grams body weight) and ambient temperatures (temperatures between 0°C and 30°C). Daily estimates of M_t for Yukon Delta birds were described by the slope of the line drawn between M_{-6} and M_{30}, extrapolating from the following allometric relationships (W equals weight in grams) described by Wiens and Innis (1974):

$$M_{30} = 0.540\ W^{0.75}, \text{ for non-passerines}$$
$$M_0 = 4.337\ W^{0.53}, \text{ for all species}$$

Body size variables for Yukon Delta waterbirds were computed as the mean weight of maximum and minimum values reported in published literature for adult male and female birds (reported in: Borodulina 1966; Mayer 1974; Terres 1980; Johnsgard 1981; Conners 1984). Because seasonal information on growth (increases in biomass) is not available for most species, initial estimates of body size were assumed as constants. Further, because it is impossible to distinguish age classes in the survey data, all birds were treated as adults. It was assumed that the linear relation between metabolic demand, body weight, and temperature was also valid for Yukon Delta birds experiencing sub-zero temperatures in early spring. Wiens and Innis (1974) noted that this extrapolation will result in an overestimation of an arctic bird's energy requirements; however, because so few birds are present on the Yukon Delta prior to May, this is probably not a serious source of error.

Other assumptions or simplfying steps were taken in the calculation of M_t. Daily temperature values were derived assuming a linear relation between the mean monthly temperatures. To compensate for daily temperature excursions and to reduce the number of iterations in the M_t calculation, one temperature per week (the temperature every 7 days) was assigned to represent the "daily" value for the preceding interval. As a result, modeled M_t values were equal for day 1 through day 7 of week 1, and so on, for weekly periods between 15 April and 15 October.

The second step in the modeling procedure was to describe the maximum amount of potential energy (value MA) available to birds for metabolism. The calculation of MA requires that all M_t estimates be adjusted to explain (1) daily activity energy expenditures, and (2) corrections associated with digestive efficency. Accordingly, M_t was increased (1) by 40% to compensate for daily activity costs, and (2) multiplied by a 1.43 correction factor that assumes a 70% digestive efficiency for all foods. This resultant product, MA, represents the total daily energy intake requirement (kcal/bird) of a free-living adult of body weight W (g) at a given ambient temperature t.

In order to reduce the large data set resulting from MA calculations without jeopardizing the integrity of the model, species-specific values of energy requirement were pooled by "species groups" and season. The net effect of this simplfying step is that daily energy budgets can be projected for "generalized or average individuals" within each species group rather than for 46 individual specific requirements. This approach is appropriate given the inherent biases of aerial surveys. Species groups included loons (2 species), cranes (1), swans (1), geese (6), dabbling ducks (5), diving ducks (8), shorebirds (15), jaegers (2), gulls (4), and terns (1).

Seasonal estimates of the daily energy requirements of the major species groups (Table 3.18) appear reasonable (all factors, especially size, considered) in a gross sense, when compared to the resting metabolic rates of other animals (Fig. 3.9). These values are comparable to M_t in this calculation. Assuming that one Watt is approximately 20 times larger than 1 kcal/d, it can be seen that the energy requirement for Yukon Delta geese shown is in good agreement with what has been reported before (i.e., an MA of about 600 kcal/d). Conceptually, the seasonal values of MA apparently reflect not only the ambient temperature conditions on the delta but (1) higher consumption by birds after spring migration is complete and prior to nesting activities on tundra habitat; (2) slightly diminished consumption rates and energy requirements of birds during summer periods of reproductive activity, egg laying, and incubation; and (3) slightly elevated metabolic demands during periods of parental care of young, and just prior to fall migration.

Literature values describing the metabolic demands of arctic birds are rare. Experimentally derived MA's for captive, adult Pacific brant (both sexes combined) averaged 414.8 ± 9.3 kcal/d ($n = 56$) between 1 May and 23 July 1973 at Fairbanks, Alaska (Morehouse 1974). The brant is a small goose, similar in size to the cackling Canada goose, or about one-half the weight of an adult white-fronted goose. Because the modeled MA represents an "average" individual from the entire "goose group," the slightly higher value is not unreasonable. Local differences in ambient temperatures, caloric content of natural versus commercial grain foods, and condition of wild versus captive birds would all contribute to differences in the total potential energy available to an individual.

The metabolism of breeding arctic shorebirds has been studied at Barrow, Alaska (Norton 1973). Mean daily existence energies of 67 and 73 kcal/bird were reported for dunlin (male and female, 55 and 60 g, respectively) and 39 and 44 kcal/bird for semipalmated sandpipers (both sexes, 25 and 30 g, respectively) during early June. By comparison, modeled existence

TABLE 3.18—Daily and seasonal energy requirements and seasonal demand on the environment of the dominant groups of Yukon Delta waterbirds.

Bird group	Daily energy requirement (kcal/bird)			Seasonal energy budget (kcal/bird)			Seasonal demand (10^6 kcal/group)		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Loons	461	416	435	27,660	25,376	26,535	14.1	28.5	31.5
Swans	918	883	898	55,080	53,863	54,778	390.6	166.5	1,025.9
Geese	546	502	520	32,760	30,622	31,720	293.7	254.0	298.2
Dabbling ducks	305	268	284	18,300	16,348	17,324	163.4	559.7	5,430.6
Diving ducks	433	380	407	25,980	23,180	24,827	252.6	128.8	95.9
Cranes	738	695	713	44,280	42,395	43,493	57.0	71.4	55.4
Shorebirds	133	109	118	7,980	6,649	7,198	18.3	39.0	1,413.5
Gulls	379	329	352	22,740	20,069	21,472	97.2	156.6	189.6
Terns	49	40	43	—	2,440	—	—	1.7	—
Total demand							1,286.9	1,406.2	8,540.6

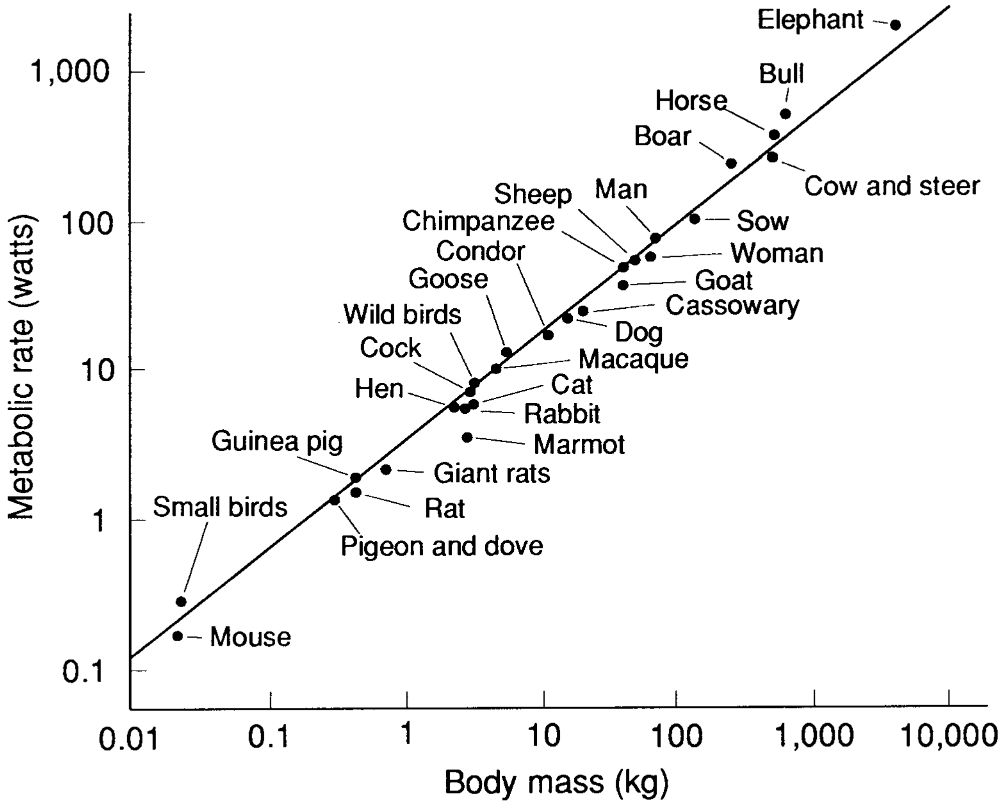

FIGURE 3.9—Metabolic rates for mammals and birds, when plotted against body mass on logarithmic coordinates. (Adapted from Knut-Schmidt-Neilson 1985.)

energies (M_t) for these species were 33.7 for dunlins (50 g) and 25.7 for semipalmated sandpipers (30 g). The modeled M_t values approximate the energy costs of Yukon Delta birds in early May, a time when delta temperature conditions (1°C) would be similar to those expected in early June at Barrow. Norton's (1973) existence energy values do not reflect metabolic costs at ambient conditions. These values reflect estimates of maximum daily energy demand computed at very low temperatures (between −10°C and −24°C); therefore, the differences in rates observed herein are probably only partially attributable to differences in body size and temperature.

The main source of difference in the experimental and modeled values appears to be in methodologies used to calculate existence energy. The maximal rates described by Norton (1973) included energy costs associated with molting and clutch production. While these costs were not ignored by Wiens and Innis (1974), they are evaluated in separate subroutines of the model, and are not included in this computation of M_t. The information needed to describe egg production costs for all Yukon Delta birds (e.g., phenologies, life histories, and habits) is presently unavailable from the Yukon Delta. Also, other minor costs associated with seasonal changes in body weight have not been considered and would contribute to differences in rate estimations. The overall result is that modeled values will consistently underestimate the total energy requirement of most Yukon Delta birds.

Seasonal energy budgets for the dominant Yukon Delta species can be projected from estimates of daily energy requirements, relative abundance information, and length of season. The spring season is described here as consisting of 60 days followed by summer and fall seasons of 61 days each. Estimated seasonal demands of individual birds within the dominant Yukon Delta groups are given in Table 3.18.

An estimate of the total seasonal demand of each species group for Yukon Delta energy reserves is possible when population information is incorporated in the analysis. The seasonal demands of each group, derived from population estimates (Table 3.16) and individual energy budgets, are shown in Table 3.18. These estimates demonstrate a similar pattern of low total energy consumption by birds on the delta in spring and summer months when compared to fall. Causes for interseasonal differences in energy demands are explained by seasonal temperature conditions, shifts in bird abundance, and related activities already described.

Although the importance of the delta to all waterbirds is apparent in all seasons, it is dramatically more important in fall. During this time, more than 75% (77%) of the energy requirement can be attributed to consumption needs of three waterbird groups: swans, dabblers, and shorebirds.

Gross estimates of the caloric requirements of the dominant waterbird species groups have been calculated for each habitat (Table 3.19). The species-level estimates have been computed by factoring seasonal composition information for each "species group." The estimates reflect seasonal energy budgets for the dominant Yukon Delta species. The "dominance" of these select species is reflected in energy demands; they account for 90% of the total population demand for spring, 95% for summer, and 83% of that predicted for fall.

The seasonal estimates indicate that 74% of the total energy demand in the Yukon Delta occurs in fall, nearly 14% in summer, and 12% in spring. In his study of four species of *Calidris* sandpipers on the tundra near Barrow, Norton (1973) estimated a total seasonal demand of about 5,000 kcal/ha (mean 4-year requirement was 3,692 kcal/ha). The estimated shorebird requirement for the Yukon Delta represents the total seasonal caloric demand of 15 species. If specific energy requirements are assumed to be equal, the seasonal data from tundra and mudflat habitats can be compared to the estimates from Barrow. Considering the areal extent of each habitat-type, it is therefore estimated that the caloric requirements for four shorebird species would be about 3,890 kcal/ha on tundra in spring. Mudflat estimates are much greater, including 9,930 kcal/ha in spring, 49,650 kcal/ha in summer, and 192,642 kcal/ha in fall. Other comparisons support the overwhelming value of mudflats to foraging birds in fall. Roughly 78% of the seasonal caloric requirement of waterbirds is obtained by foraging in mudflat areas (17.3% from tundra, and 4.7% from coastal areas).

The increased importance of coastal mudflats in fall by swans, dabblers, and shorebirds is significant considering the populations they represent. Several of the waterfowl comprise major segments of Yukon–Kuskokwim Delta and Alaska Flyway populations (Table 3.14). It has been estimated that nearly 20% of the region's population of tundra swans (several tens of thousands) and 40% of the pintails (a few hundred thousand) are present on Yukon Delta mudflats during late August–September (Eldridge 1987). This use represents 10% of the Alaskan populations for these birds. In the case of tundra swans, the numbers represent about 10% of the entire estimated North American population.

The true magnitude of shorebird foraging on Yukon Delta mudflats is unknown and in all likelihood has been underestimated since shorebirds tend to be poorly accounted for in aerial surveys. Species occupying habitats other than exposed mudflats are extremely difficult to see. It has been reported, however, that between 30 and 60% of regional (and in somes cases, Alaskan) shorebird populations may be found on the Yukon Delta mudflats in the fall (Eldridge 1987). The source of these birds is not known. It seems unlikely that all of the birds using the delta mudflats in the fall are summer residents (juveniles and adult birds) of this area. It is more probable that fall populations are composed of migrant shorebirds en route to southern wintering areas from summer habitats elsewhere (e.g., Seward Peninsula and North Slope). Such "stopovers" for rest and feeding have been noted for shorebirds on

TABLE 3.19—Energy requirements (10^6 kcal) of the dominant Yukon Delta waterbirds by season and habitat.

Species group	Spring			Summer			Fall		
	Mudflat	Coastal	Tundra	Mudflat	Coastal	Tundra	Mudflat	Coastal	Tundra
Loons	0	1.6	12.6	0.9	0	27.6	4.7	4.4	22.4
Swans	156.2	39.1	195.3	108.2	0	58.3	748.9	0	277.0
Geese	143.9	8.8	70.3	198.1	0	43.2	122.3	6.0	152.1
Dabbling ducks	60.5	3.3	76.8	481.3	16.8	50.4	3,747.1	0	325.8
Diving ducks	5.1	197.0	30.3	42.5	43.8	20.6	0	66.2	27.8
Shorebirds	7.7	0	7.7	37.4	0	0	1,385.2	0	0
Gulls	23.3	0	45.7	79.9	17.2	31.3	119.4	36.0	20.9
Terns	0	13.6	0	0.2	0.1	1.4	0	0	0
Cranes	0	0	57.0	0	0	71.4	21.1	0	34.3
Total	396.7	263.4	495.7	948.5	77.9	304.2	6,148.7	112.6	860.3

the Copper River Delta during their seasonal migrations to the Bering Sea (Senner and Norton 1976).

The increased bird occupation of the Yukon Delta wetlands during the fall underscores the relationship between this area for autumnal foraging and fall migrations. Since many birds are only seasonal residents of the Yukon–Kuskokwim wetlands, late August and September postnesting periods are times of rapid energy acquisition. This energy is stored as fat within the individual, a prerequisite for long-distance migrations. The narrow coastal mudflats and intertidal waters fringing the Yukon Delta (1–1.5 km from shore) apparently provide an easily accessible source of invertebrate and plant foods (Kirchhoff 1978). The transitional nature of the intertidal habitat between terrestrial, riverine, and nearshore ecosystems is probably responsible for the apparent abundance of invertebrate foods. The ecology of the mudflat environment, while of utmost importance to foraging waterbirds, remains poorly understood.

The daily environmental demand (kcal/m^2) of arctic birds on the Yukon Delta can be further examined in a "community analysis" similar to that described by Wiens and Innis (1974). Environmental demand, or ERA in the model, is derived by:

ERA = MA (AP); where

ERA = the total daily energy demand of the adult population (kcal/m^2);

MA = the total daily energy intake requirement (kcal/bird) of a free-living adult of body weight W (g) at a given ambient temperature; and

AP = the adult population density (birds/m^2).

The total daily caloric demand of Yukon Delta waterbirds is about 0.1–0.2 kcal/m^2 (Table 3.20). Seasonal changes in abundance as well as changes in habitat use are reflected in the ERA values. There is an obvious increase in energy requirements with advancing season. Almost 10 times as much energy is extracted from delta habitats in the fall as compared to spring. Of the total estimated demand, 90% of the energy is derived from the mudflat habitat, and 80% of this during fall. The tundra habitat is next in relative importance, providing nearly 8% of the Yukon Delta population's energy needs. In each season, less than 1% of the total avian energy requirement is met from coastal waters. While coastal waters may provide important seasonal foraging habitat to a small number of user species, they appear to play a relatively insignificant role overall.

The Yukon Delta mudflats appear to provide a consistently superior source of metabolizable energy to waterbirds compared to the other habitat types. During spring, 62% and 32% of the total caloric demand of birds was on mudflats and tundra, respectively. Similarly, in summer, 89% and 10% of the total caloric demand was procured from these respective areas. In fall, waterbird competiton for food sources on the spatially more limited mudflat habitat is more spectacular, with almost 95% of the estimated daily environmental demand (140,009 × 10^{-6} kcal/m^2) for this season being placed on mudflats.

The most obvious feature of waterbird use of the Yukon Delta is the great reliance by many species on the mudflat habitat. Other less obvious patterns emerge

TABLE 3.20—Daily energy demand (ERA) (10^{-6} kcal/m^2) of the dominant Yukon Delta waterbirds on their environment by season and habitat.

Species group	Spring			Summer			Fall		
	Mudflat	Coastal	Tundra	Mudflat	Coastal	Tundra	Mudflat	Coastal	Tundra
Loons	0	4.61	106.0	20.8	0	220.5	104.4	13.0	178.3
Swans	3,616.9	119.3	1,643.2	2,463.6	0	485.9	17,053.0	0	2,289.9
Geese	3,330.6	27.3	1,064.7	4,513.0	0	356.4	2,782.0	15.6	1,258.4
Dabbling ducks	1,399.9	9.1	646.6	10,961.2	50.9	418.1	85,316.4	320.9	2,698.0
Diving ducks	116.9	593.2	255.5	969.0	129.2	171.0	0	191.3	223.8
Shorebirds	178.2	0	178.2	853.5	0	0	31,540.2	0	0
Gulls	542.0	41.7	386.6	1,819.4	52.6	259.9	2,721.0	105.6	172.5
Terns	10.3	0.49	5.4	4.8	0.4	11.2	14.6	0	0.4
Cranes	0	0	479.7	0	0	590.7	477.7	0	285.2
Total	9,194.8	795.7	4,765.9	21,605.3	233.1	2,513.7	140,009.3	646.4	7,106.5

upon closer inspection of the ERA attributes. Energy demands on tundra and coastal habitats were higher in spring than in summer, and highest overall in fall. The increased ERA values are most dramatic in the tundra environment in fall. Estimates of demand in fall comprised 51.5% of the total seasonal demand by birds of this habitat. The total demand on the tundra environment represented 16.5% of that estimated for the entire Yukon Delta. Because topographic relief is so low along the delta margins, and given known food habits (grasses and sedges) and unknown daily foraging movements of some waterfowl (and other birds), it is conceivable that distinctive bird demands on mudflat and tundra habitats may not be as severe as indicated by the ERA values.

The nearshore waters of the Yukon Delta are among the earliest in Norton Sound to become free of shorefast ice in the spring. Although the delta is not especially close to any seabird colonies, the opening of leads provides foraging habitat for migrant birds (including seabirds) bound for other locations, as well as early-arriving diving ducks. As coastal waters become more widely accessible in the spring and early summer, these birds likely disperse to equally productive nearshore feeding grounds closer to their nesting habitats. The increased densities and foraging of diving species in the fall may reflect movement of adults and juveniles off tundra nesting and rearing sites prior to migration. As has been mentioned, some of the increase may be attributed to transient species laying over for brief refueling of depleted or dwindling energy reserves. The 1986 data indicate that the coastal habitat does not attract large numbers of foraging birds. There is, however, a fairly strong and consistent use of this habitat by black scoters throughout the open water season.

As has been emphasized, the Yukon Delta mudflats provide prime foraging habitat to large numbers of swans, ducks, geese, and shorebirds, especially in fall. The daily metabolic demands (10^{-6} kcal/m^2) of these four groups (swans, 748.9; geese, 122.3; dabbling ducks, 3,747.1; shorebirds, 1,385.2) represent approximately 98% of the total fall consumption. A short coastal segment of mudflats lying between the Middle and North mouths of the Yukon River, encompassing approximately 140 km^2 (20% of available mudflats), has been identified as an extremely productive feeding area for these birds in fall (Jones and Kirchhoff 1978; Ernst 1986; Eldridge 1987). This is also substantiated in estimates of consumption by ducks, swans, and shorebirds on mudflats in fall; roughly 95% of all the energy derived from all delta habitats in fall is accounted for by these three groups on the mudflats. Frequency of occurrence data of Ernst (1986) and Eldridge (1987) indicate that 72% of the tundra swans and 68% of northern pintails found on the Yukon Delta in fall are distributed across 35 km of mudflats located between the North and South mouths of the river. Assuming that the shorebird group is evenly distributed across all Yukon Delta mudflats in fall, roughly 20% of this group would be found on the interdistributary mudflat expanse.

The seasonal importance of the Yukon Delta mudflats to the welfare of tundra swan, dabbling duck, and shorebird populations can be conservatively evaluated in a determination of how well this environment meets these birds' physiological requirements for fall migrations. During fall, the Yukon Delta mudflats supply an estimated $5{,}881.2 \times 10^{-6}$ kcal/m^2 a day to these birds. This represents 38% of the expected total caloric requirement of all delta birds during this period. An estimated $2{,}705 \times 10^{-6}$ kcal/m^2 a day is directly related to swan (ERA = 539 or 72% of all mudflat foraging), dabbler (ERA = 1,889 or 50%), and shorebird (ERA = 277 or 20%) consumption on the relatively small mudflat zone lying between the two river mouths.

Autumnal foraging of birds on this interdistributary mudflat may account for more than 50% of the entire seasonal demand by waterbirds on the Yukon Delta. Conservative estimates of the energy requirements of the dominant species in fall (swans, 5.6% of total seasonal demand; dabbling ducks, 19.7%; shorebirds, 2.9%) would suggest that consumption on the mudflats at this time constitutes more than 28% of the delta's entire avian energy budget.

Those portions of the tundra that are used for nesting and rearing by birds are of vital significance in maintaining the delta populations. Their actual contribution in an ecological sense has not been fully treated here and such treatment is not possible within the context of existing data. Summer foraging on mudflats appears to an important activity of many species, and energy sources derived there may be a major determinant of clutch success.

Of all habitats, the mudflats are the most spatially limiting and energy-rich. Perhaps no example illustrates the ecological importance of the mudflats as well as the extensive avian use of the 35 km of coastal mudflats between the North and South mouths of the Yukon River. Of all the areas discussed, this short segment of beach is clearly the most important to birds of the Yukon Delta. In a regional sense, its bioenergetic contribution to the well-being of large portions of Alaskan and North American populations of tundra swans, northern pintails, and, to an unknown degree, shorebirds, may be unsurpassed in the fall.

3.5 YUKON DELTA MAMMALS

Mammals that frequent the Yukon Delta can be classified into two basic groups: coastal/marine and terrestrial/riparian (floodplain-inhabiting). Members of both groups play important roles in the ecosystem of the Yukon Delta through interactions with other important biotic resources and by providing important subsistence resources to human inhabitants of the area.

3.5.1 Coastal/Marine Mammals

The predominant marine mammals found in or near the Yukon Delta are belukha whale, ringed seal, spotted seal, and bearded seal. All of these play a part in the subsistence economy of the human inhabitants of the area.

Marine mammals that occur in offshore areas of the Norton Basin and could be expected to occur infrequently in the delta are walrus, northern sea lion, and polar bear. The harbor porpoise is occasionally seen in coastal Norton Sound. Since it quite frequently occurs within estuaries, it could also be expected to occur in or near the Yukon River mouth. This rather shy animal is not easy to approach, and little is known about its distribution and abundance in Norton Sound. It is most frequently observed in pairs or small groups.

In addition to the above species, gray whales are seen in the deeper offshore areas to the north and northwest of the Yukon Delta. These animals are common from May to November (Zimmerman 1982) and represent part of the eastern Pacific stock of gray whales (Cowles 1981) that winters near the coast of Baja California and summers in the Bering, Chukchi, and western Beaufort seas.

Wolfe (1981) pointed out that harvest levels of a particular food reflect the community's geographic location along the lower Yukon River. Sea mammal harvests dominate the coastal communities and land mammal harvests dominate the more inland communities. However, either through trade or direct hunting by members of a community, even an inland community such as Mountain Village obtains marine mammal products as part of its economy. For example, Wolfe (1981) indicated that marine mammals account for 6–25% of the diet for inhabitants of the Yukon Delta coastal communities. This compares to 30–50% of the diet in the more marine-oriented communities of Stebbins and St. Michael to the north of the delta.

Belukha whales are common in the region of the Yukon Delta from spring through autumn. They appear in nearshore areas during ice breakup and the arrival of spawning herring and salmon (April–May), and leave the area by late September or early October. One of the three main summer concentration areas for belukhas in the Bering Sea is at the mouths of the Yukon River (all three distributaries). Although the belukhas of Norton Sound feed on saffron cod, sculpin, smelt, capelin, herring, salmon, and other species of fish (Nelson 1980; Seaman and Burns 1981) during their concentration at the mouths of the Yukon River, they are probably concentrating their feeding on salmon (both adults and juveniles).

The shallow waters of the Yukon Delta provide suitable summer habitat for the belukha in terms of food (fish) and relatively warm waters for calving. Of the 12,000–16,000 belukhas in the Bering Sea, about 3,000 spend the summer in the coastal regions of the Bering and the rest migrate through the Bering Strait into the Chukchi and Beaufort Seas. It is not known what proportion of this remaining Bering Sea population frequents the Yukon Delta; however, the largest single sighting was 100 animals feeding off the river mouth in July 1981 (Frost et al. 1982).

Concentrations of the belukhas at the mouth of Yukon River and their movement up into the distributaries during the summer make them readily accessible to local subsistence hunters. During this period, however, subsistence efforts are directed more toward the fisheries and, although these marine mammals are taken when the opportunity arises, it is usually not a directed, organized hunt. The period of harvest for these animals is mid-June through September.

Three species of phocid seals (spotted, ringed, and bearded) commonly frequent the Yukon Delta or area immediately offshore. A fourth species (ribbon seal) may be an infrequent inhabitant of the delta area; however, there are no documented observations of this species in this part of Norton Sound. Both the associations of the animals with ice and their food sources determine their presence in and utilization of the resources of the Yukon Delta.

The ***spotted seal*** winters at the southern edge of the sea ice pack. Most of the adult population spends the summer along the coasts of the Bering and Chukchi seas, generally following the ice edge as it advances and retreats. However, a portion of the population remains in the Bering Sea during the summer and is quite common. During certain periods of the summer it is quite abundant in the area.

The summer diet of the spotted seal is similar to those of the belukha whale and the ringed seal, consisting of Arctic cod, saffron cod, capelin, pollock, herring, sand lance, sculpin, shrimp, and salmon. Because of their belukha-like behavior (i.e., concentrating at the distributary mouths to feed on salmon during the spring–fall months), the spotted seal is probably the seal most commonly seen, and the most commonly taken, by subsistence hunters during the fishing season.

Spotted seals (in fact, all seals) are harvested in the Yukon Delta during two periods: (1) the open-water period of the summer, with most effort during September and October, and (2) during March through April (Wolfe 1981). The summer harvests consist of incidental take of animals in the river during fishing activities and directed hunts in the fall before freeze-up. During the winter, the spotted seal occupies the edge of the landfast ice and the lead systems. During March–April and sometimes earlier, hunters from the delta villages travel as much as 50 km out to the ice edge to hunt this species. Other seals, such as bearded and ringed seals, are harvested if encountered at this time.

The ***bearded seal*** is a solitary animal, generally characteristic of drifting sea ice. It is a benthic feeder, its principal food being similar to that of the Pacific walrus: clams, shrimps, and brachyuran crabs. Most of the Bering and Chukchi sea population winters along the southern ice edge, placing a portion of this wintering habitat at the land-fast ice edge, offshore of the delta. Here this species uses the cracks and leads in the ice for haulout. During March–April and sometimes earlier, hunters from the delta villages travel to the ice edge to hunt for seals.

During the spring and before the pack ice breaks up, most of the bearded seals migrate northward through the Bering Strait and into the Arctic Ocean. Some juveniles remain in the Bering Sea all summer (Burns 1978). These immature animals tend to feed on shrimp (Lowry et al. 1979, 1980). Subsistence harvest of bearded seals during the ice-free period is incidental, and usually occurs along the coast during late August–October, right before freeze-up (Wolfe 1981).

Like the bearded seal, the ***ringed seal*** is primarily a resident of the Yukon Delta during the period that ice is present (November–May) and, except for some juvenile animals that stay in the area during the summer, spends the rest of the year in the Arctic Ocean. Unlike the bearded seal, ringed seals are usually associated with shorefast rather than drifting sea ice. During the ice period, the highest densities of ringed seal are found in areas of landfast ice where the seals breed and give birth to pups (Burns et al. 1981). Prior to ice breakup (March–April), hunters from lower Yukon River villages take this species and others in spring seal hunts.

The principal food of the ringed seal in Norton Sound consists of arctic and saffron cod (Lowry et al. 1980, 1981). The juveniles that remain during the summer are also known to feed on sculpins and on invertebrates such as shrimps, mysids, and amphipods (Truett and Craig 1985). The most important habitat for ringed seals in the Norton Basin is apparently the deeper areas of landfast ice. The extensive, shallow areas found along the Yukon Delta may not provide as good a feeding habitat as deeper waters.

3.5.2 Terrestrial/Riparian Mammals

Riparian mammals are those terrestrial mammals that inhabit the riverbank or floodplain of a river system. In the case of the Yukon Delta, this fauna is dominated by the small furbearers (Arctic and snowshoe hares, Arctic and red foxes, beaver, marten, mink, muskrat, and land otter), all of which play important roles in the socioeconomics of the region. The human use of fur-bearing species in fall/winter periods provides a mixed economy of commercial trapping for furs (muskrat, beaver, mink, marten, fox, and land otter) and subsistence (muskrat, snowshoe hare, tundra hare, beaver, and land otter).

Arctic foxes are the primary predators of the nests of cackling Canada geese, emperor geese, white-fronted geese, and black brant (Stehn 1987). Additional losses from parasitic jaegers, glaucous gulls, and mink also occur. Fox predation can be a major factor limiting production of the above species (Dzimbal et al. 1984; Petersen 1984; Scanlon and Jarvis 1984; Sedinger 1984). Stehn (1987) pointed out that alternate foods for the fox, such as tundra vole, may be an important component influencing fox predation on goose nests. High fox predation on goose nests seems to correlate with high fox numbers, lack of active dens with kits, and low microtine abundance.

Chapter 4

Ecological Processes

4.1 COASTAL INFLUENCE OF THE YUKON RIVER

Very large rivers, such as the Mississippi, lack significant estuaries. Their discharge rates are so great that estuarine processes are overshadowed by the fresh water and sediments that move through the system (Darnell and Soniat 1979). Rather than serving as an "ecological pass" for estuary-shelf interactions, they are more aptly described as "pass-through" systems. In the case of the Yukon River, this condition is probably seasonal, with the lower river functioning as a pass-through system during summer, the period of high discharge, and as an estuarine exchange system during other seasons.

During summer periods of high river discharge, the Yukon River dominates the delta from nearshore to 30 km offshore. North- to northwest-flowing river water merges near the delta front with Alaska Coastal Water. Until recently, it was thought that land-derived nutrients (particulate and dissolved materials) associated with the Yukon River discharge (nitrate content about 10 μM/liter; McRoy 1987) would sustain high levels of primary production in inner shelf waters (the shelf inside the 50-m depth contour) throughout the summer (Sambrotto et al. 1984). Nutrient sampling in Shpanberg Strait, located between St. Lawrence Island and mainland Alaska, does not confirm such coastal enrichment (McRoy 1985). Analysis of nitrate samples collected off the Yukon River in 1983 and 1984 by ISHTAR researchers indicated barely detectable levels at the surface in June and throughout the water column in August. Satellite imagery of the Yukon Delta in July 1985 shows suspended sediment transport to be coastally confined and across the entrance to Norton Sound (McRoy 1985).

Similar patterns of water mass transport have been described for delta waters at slightly greater than 10 m of depth (McDowell et al. 1987). An offshore current meter moored to the west of Middle Mouth in June 1986 indicated a mean longshore current of 12 cm/s. Nearly all Yukon River water discharged from the South Mouth is advected to the north after an expected Yukon Delta residence of less than 1 week. This flow regime could be expected to persist, and perhaps strengthen, during the summer, when the Yukon River discharge is high and winds are either variable or predominantly from the south.

4.2 CARBON BUDGETING AND ENERGY PATHWAYS

The annual carbon budgets and energy pathways that have been described for inner shelf waters near the Yukon Delta (Fig. 4.1), largely as a result of ISHTAR research, provide the best information available describing the geographic influence of the Yukon River on regional biotic productivity. Sambrotto et al. (1984), McRoy (1985), and Walsh (1985) described parameter estimation procedures, including assumptions. McRoy (1985) estimated carbon utilization by birds, fish, and mammals. In this report the production values are discussed with respect to (1) annual carbon budgets that have been developed for the southeastern Bering Sea (Walsh and McRoy 1986), and (2) regional comparisons in resource abundance described by Zimmerman (1982).

The annual primary production of inner shelf waters of Norton Sound was calculated using an estimate for the total daily nitrogen uptake rate by phytoplankton, an assumed growing season of 150 days (June to October), and a C/N ratio of 6:1. The result is 50 g C/m^2 produced in Alaska Coastal Water annually, which reflects a daily production rate of 0.33 g C/m^2 composed of: (1) 0.1 g C/m^2 resulting from an estimated daily uptake of 0.01 g NO$_3$/m^2 by phytoplankton; (2) 0.03 g C/m^2 resulting from an estimated daily ammonia uptake by phytoplankton of 0.31 mmol NH$_4$/m^2; and (3) 0.2 g C/m^2 produced from recycled nitrogen supplied as excretory products of bacteria and zooplankton (McRoy 1986). Approximately 70% of the daily carbon production may be supported by recycled nitrogen.

The mean annual food requirement of small benthic organisms (microflora, microfauna, and meiofauna) was estimated to be 25.1 g C/m^2. This estimate assumes a daily residential consumption rate of 6–9 mmol C/m^2 in summer (June through September) and a 60% lower

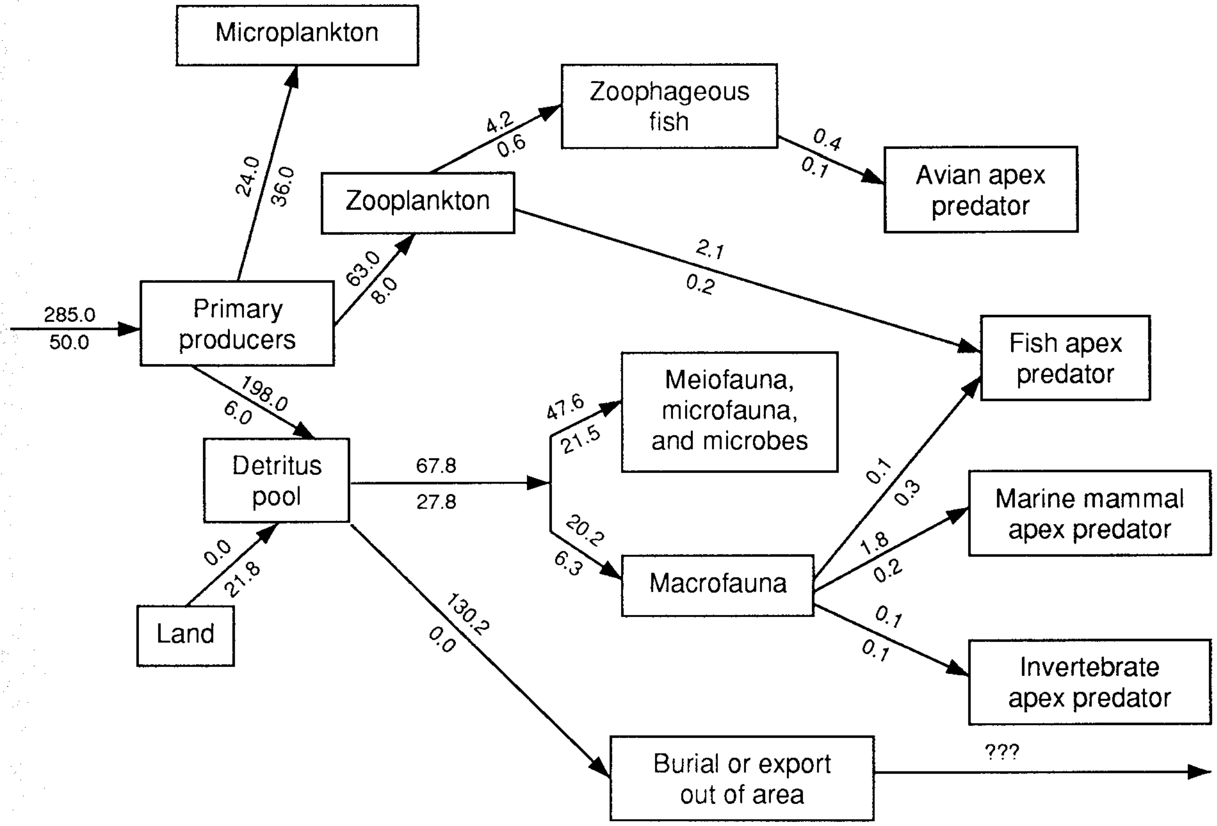

FIGURE 4.1—Annual carbon flow (g C/m^2) in Bering Shelf/Anadyr Water (upper value) and Alaska Coastal Water (lower value) in the northern Bering Sea and Chukchi Sea. (Adapted from McRoy 1987.)

consumption during the remainder of the year. This estimate does not include consideration of the metabolic carbon demands of the infaunal biomass (macrofauna—molluscs and polychaetes), which were estimated to be 2.7 g C/m^2 annually from an observed macrofaunal abundance of 58 g wet weight/m^2. The total annual benthic demand of inner shelf waters would be about 27.6 g C/m^2 or about half the annual primary productivity of Alaska Coastal Water (McRoy 1985).

Estimates of bacterial production were made from shipboard experiments conducted during PROBES and ISHTAR cruises. The bacterioplankton biomass in Alaska Coastal Water was estimated to be 13.5 mg C/m^3, with daily growth rates of 2.7–5.0%. Daily bacterial production rates in the Bering Sea range between 0.4 and 0.6 mg C/m^2. Assuming a 90% loss of the bacterioplankton over the 150-day growing season results in an annual phyto-detrital carbon loss of approximately 36 g C/m^2. Estimated nitrogen metabolism rates of phytoplankton and detritus by benthos could result in as much as 36 mg N/m^2 potentially available per day via resuspension and other mixing processes to the euphotic zone of the inner shelf. This would explain the excretory supplement of recycled nitrogen needed by bacteria and benthos to sustain the observed daily production rates of organic matter (McRoy 1985).

The zooplankton community grazing on inner shelf primary production was found to comprise many of the same species as had been identified in middle shelf and coastal waters of the southeastern Bering Sea (Neimark 1979; Cooney 1981; Smith and Vidal 1986). These zooplankton predominantly include smaller species (body size less than 2 mm) such as *Pseudocalanus* spp. and *Acartia clausi*. The taxonomic composition of zooplankton in the Bering Sea is similar to dominants described in the southeastern Chukchi Sea (Hameedi 1988), shelf waters of the Gulf of Alaska (Cooney 1987), and inside waters of southeastern Alaska (Coyle and Paul 1988). In Norton Sound, zooplankton were estimated to consume approximately 0.05 g C/m^2, or 16% of the estimated daily carbon production. In a review of published literature, Coyle and Paul (1988) suggested that copepod grazers consume an average of 11% of their body carbon per day (seasonal range = 3–16%).

The ISHTAR carbon budget for inner shelf waters of the northern Bering Sea indicates a total annual secondary consumption of carbon (zooplankton +

bacterioplankton + benthos) of 71.6 g C/m². This is 21.6 g C/m² more than the 50 g C/m² estimated to be produced *in situ.* Assuming no transport of particulate organic carbon through the Bering Strait, the Yukon River is, therefore, thought to annually export at least 21.6 g C/m² to the inner shelf, and probably more.

Burns et al. (1982) found the average demersal fish and invertebrate resources in Norton Sound (2.7 kg/m²) to be approximately 4.5 times less abundant than in the southeastern Bering Sea (11.7 kg/m²). The southeastern Bering Sea biomass consisted of 9.0 kg/m² of fish and 2.3 kg/m² of invertebrate consumers, while in Norton Sound the biomasses were 0.4 kg/m² and 1.6 kg/m², respectively. In Norton Sound, more than 90% of the invertebrate biomass was composed of echinoderms.

These values reflect a greater than five-fold difference in the average fish biomass in the south-eastern Bering Sea. Assuming zooplankton consumption by fish in Norton Sound and the middle shelf domain of the southeastern Bering Sea (Walsh and McRoy 1986) is similar in biomass explains the 0.2 g C/m² annual carbon utilization estimate at this trophic level. Other transfer pathways from the macrobenthos to apex predators reflect the standard 10% efficiency at each step. This approach was followed by Walsh and McRoy (1986) in their development of annual carbon budgets for the outer shelf domain in the southeastern Bering Sea. How this 10% is divided among higher trophic groups (fish, invertebrates, birds, and mammals) in the proposed ISHTAR energy budget is not explained. The various allocations are probably related to regional resource distribution and abundance (e.g., high use of the benthos by gray whales, walrus, and bearded seals, or smaller bird colonies in the northern than in the southern Bering Sea) and carbon transfer relationships decribed by PROBES (Hood 1986).

In view of the existing information, McRoy (1987) suggested that a single primary production event occurs in coastal waters in early summer. The bloom occurs soon after sea ice is gone. For the remainder of the ice-free season, nearshore areas are characterized by low phytoplankton biomass (chlorophyll *a*) and productivity. The energy budget described by ISHTAR suggests complete utilization of marine and terrestrial carbon within nearshore waters (Alaska Coastal Water). The magnitude and fate of Yukon River particulate exports are currently being examined in ecosystem simulations (Walsh and McRoy 1986). The annual energy budget is preliminary and has been developed to illustrate the relative importance of the nutrient-laden waters of the western Bering Sea to regional ecosystems located downstream. The model reflects gross patterns of carbon transfer and is not comprehensive; for instance, energy transfers between the microbenthos, macrobenthos, and detrital pool are not described. Finally, it is a generalized model and does not reflect the true ecology of inner Norton Bay, a depositional environment characterized by extremely sluggish circulation and elevated epibenthic biomass (Zimmerman 1982).

4.3 RESOURCE SPIRALING AND TRANSITIONAL ZONES

The Yukon–Kuskokwim Delta is subject to extreme environmental conditions. The nearshore experiences high freshwater inputs and sediment reworking during summer, and extensive icing in winter. These processes, and the tendency of research to focus on "valued ecosystem components," have resulted in a lack of knowledge regarding the less apparent spatial and temporal habitat relationships on the Yukon Delta. This is especially true of the roles of invertebrates (such as aquatic insects) and certain vascular plants as storers and exporters of energy in local food webs.

Much of the Yukon River's detritus, dissolved nutrients, and sediment load is transported to inner shelf and Norton Bay waters. Of this, a majority is delivered directly to the delta front, bypassing other deltaic habitats. It is likely that relatively little river water is transported directly into inshore zones.

During the summer, wetlands and other vegetated lowland areas, with associated mudflats, function as reservoirs of particulate organic matter, nutrients, and insects. These resources are slowly but continuously released or carried into coastal habitats. Their transport is probably related to snowmelt, rainfall, winds and breezes, or high-water events, associated tides or storm surges; processes that also influence the erosional or depositional processes of a delta. Other transfer mechanisms probably involve the metabolic processing of organic matter and nutrients by birds and mammals living in coastal habitats. The relative seasonal importance of physical and biological factors affecting mudflat erosion or deposition is summarized in Figure 4.2.

The Yukon Delta supports a species-rich vegetative cover in various transitional zones from upland to intertidal. Generally, the vegetation is dominated by low shrubs in the uplands, willows and other "wet" species associations along deltaic waterways, grass and sedge stands on coastal wetlands, and pondweed stands in more aquatic zones of river influence. All of the plant life, especially those species nearest the river or the delta coastline, are sources of invertebrate and vertebrate food through either direct consumption or detrital

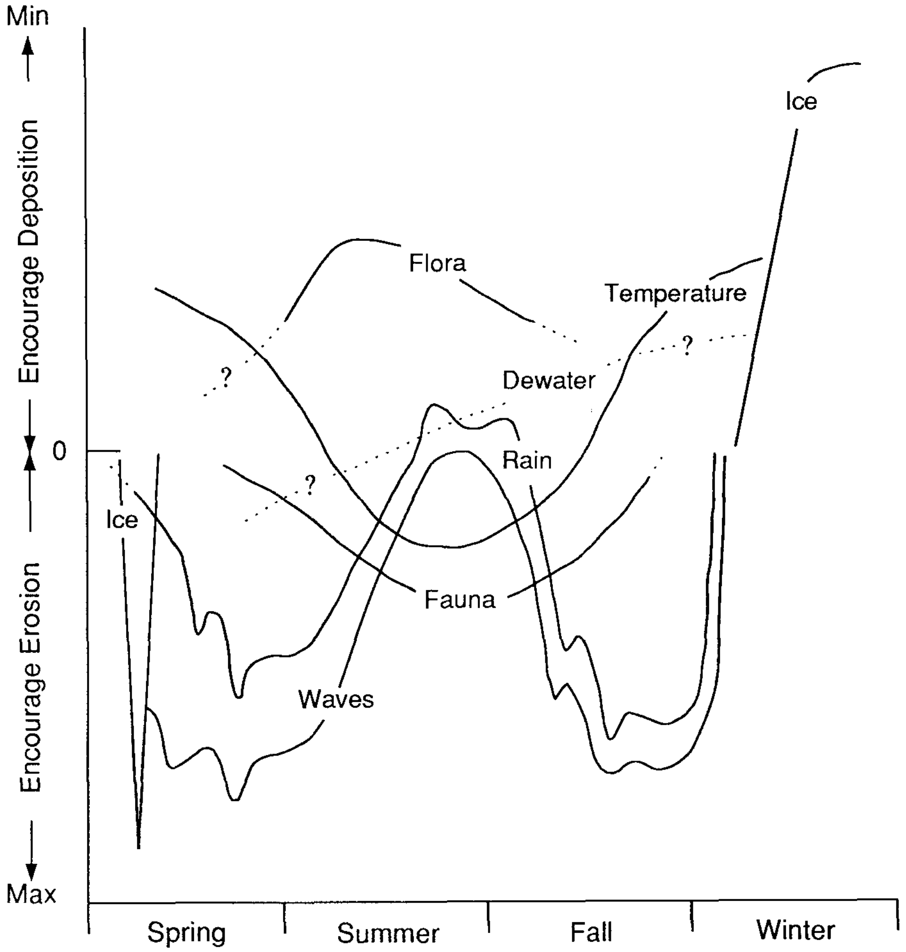

FIGURE 4.2—Relative seasonal importance of the major physical and biological factors affecting intertidal sedimentation. (Redrawn from Anderson 1983.)

food webs. Riverine and wetland plants provide important refuge habitat to many terrestrial insects. Because of their close proximity to the river, these species often become major components of the invertebrate drift either by accident (e.g., falling or carried with plant) or via use of the water's surface for various purposes (e.g., feeding or reproduction).

The plants can also serve as a trap, or sink, for air- or water-borne nutrients that might otherwise be transported offshore. In mudflats of intertidal, coastal slough, and pond habitats, primary production is dominated by algal matting on otherwise barren sediments. Grasses and sedges (*Carex, Puccinellia,* and *Triglochin* species) are dominant plants in the lush intertidal meadows, and pondweed (*Potamogeton* sp.) is found in the intertidal zone between the middle and north distributaries. The nutrients stored in these plants provide an important food source for nesting and migratory waterfowl throughout the summer and early fall.

Vascular plants are a major source of particulate detritus in river, pond, and coastal habitats. Where this energy is introduced into the Yukon River watershed will have the greatest affect on the structure and function of aquatic microbial and invertebrate life found in a particular reach of the river. Shredding organisms and microbes in inorganic sediments are the first to act on the particulate detritus and are most abundant nearest the upriver and tributary sources. Downstream, communities tend to shift to filter feeding dominants which are better able to utilize finer detrital particles, and numbers of predatory species increase.

The movement of a "particle" downstream within a river system can be described by the concept of "resource spiraling" (Elwood et al. 1983). A single particle is continuously being retained in a portion of the system (bottom sediments) and released to the flowing waters, then retained and released again. This process continues until the particle moves out of the system. The resource spiraling concept provides a spatial and temporal framework from which to view nutrient cycling and the processing of organic matter in a river (the concept can probably be expanded to include the aquatic insects exhibiting behavioral drift). Nutrients supplied from the surrounding watershed are retained and used with various degrees of success along the river. In the Yukon River, population and community attributes that might enhance the retention and use of nutrients are not known but would be different in the different river conditions common to the lower river (Fig. 4.3).

Ecosystem Parameters	**Geomorphic Features**		
	Canyon	**Braided**	**Meandering**
			
Stream surface area: discharge	Low	High	Medium
Riparian inputs	Low	High	Medium
Detrital storage	Low	High	Medium-high
Area flooded	Small	Large	Medium

FIGURE 4.3—Shifts in important ecosystem parameters in response to changes in geomorphic features resulting from differences in hydraulic dynamics at different points in a stream reach. (Adapted from Minshall et al. 1985.)

Backwater channels and sloughs, common to the lower Yukon River, are so sluggish for the majority of the summer months, after initial ice breakup and associated runoff, that invertebrate communities are likely to be very similar to those found in lakes and ponds.

The OCSEAP studies were not designed to provide quantitative information on the invertebrate resources of the Yukon Delta. From stream invertebrate studies conducted elsewhere, it is evident that the inventory provided in this report probably contains only a small fraction (<10%) of the total number of species actually present. Without species-specific information on community structure and function in various habitats it is difficult to identify the major potential pathways of instream nutrient cycling and their localized or transportative effects on riverine and coastal productivities. Simply stated, there is too much variation in functional feeding morphologies among aquatic invertebrates to speculate on invertebrate resource use and major carbon flows.

4.4 IMPORTANT HABITAT RELATIONSHIPS

Apparent trends in dominant invertebrate occurrence and use of deltaic habitats can be generalized for the open water periods. In summer the majority of drift insects (chironomids, mayflies, and stone flies) are derived from both terrestrial (adults) and aquatic (larvae and nymphs) habitats. Their abundance can be related to high river discharge and the emergence of adults in river and wetland habitats each spring. The timing of emergence appears to be a factor of great importance in the initiation and promotion of deltaic food webs, as indicated by their dietary importance to anadromous fish and shorebirds in early summer each year.

In the lower Yukon River, the planktonic fauna comprises a mix of marine and freshwater forms, a pattern indicative of estuarine conditions. Freshwater forms are most closely associated with the Yukon River water in contrast to estuarine and marine components found in mixing zones, or deltaic platform and channel waters where some structure may exist. A freshwater–estuarine copepod (*Epischura* sp.), several cladocerans, and rotifers were predominant in the freshest waters. Other calanoid and harpacticoid copepods (*Eurytemora* sp. and *Tachidius* sp.), were found in major distributary habitats but were more consistently reported in brackish waters of the delta front and platform, and in areas of minor river discharge. Intertidal mudflats, sloughs, and other coastal habitats provided habitat for many epibenthic crustaceans, including mysids (*Neomysis intermedia, Mysis littoralis*), isopods (*Saduria entomon*), several species of amphipods, several species of nematodes, polychaetes, an intertidal beetle, various bivalve molluscs, and a large number of aquatic dipterans. Farther offshore in delta front and platform waters, only the mysid *Neomysis* sp. was consistently reported in gut analyses.

The coastal sloughs and vegetated mudflats may be the most important Yukon Delta habitats. Of the numerous habitats examined, intertidal mudflats and coastal sloughs provide transitional environments between terrestrial and estuarine zones. The large number of different infaunal and epibenthic invertebrates reported from these habitats is indicative of an area where energy processing and cycling is active. Although not demonstrated by the OCSEAP surveys, mineral cycling processes in the meiofaunal component of the infaunal standing crop are likely to be crucial in the chemical energy transformations responsible for the suspected productivities of these habitats. Nematodes are apt to be one of the key species driving invertebrate food webs (Fig. 4.4). Benthic amphipods are probably an intermediate trophic level between nematodes and apex consumers.

Nutrients and particulate matter are of terrestrial, riverine, and estuarine/marine derivation. Both physical and biological processes deliver terrestrial products and have been previously described. Riverine nutrients and detritus are transported either directly during periods of low flow or via coastal mixing and delivery with estuarine/marine detritus. Tidal forcing within the delta's complex network of interdistributary channels is the major conduit for onshore deliveries. Deltaic tidal mudflats probably interact more with these subtidal stream channels than do sloughs, because tides inundate tideflats daily and transport less material to the more backwater areas (sloughs).

The invertebrate fauna reported from the intertidal sloughs and mudflats comprise the most diverse assemblage yet encountered from fish food habit compilations. The mudflats and sloughs located near the Middle and North mouths of the Yukon River are important summer feeding habitat for many species of nesting and migrating shorebirds, waterfowl, and andromous fish. Larval and adult chironomids are important foods of shorebirds and fish early in the summer. Other invertebrates, such as epibenthic crustaceans, are important in whitefish and sheefish diets during their summer residence. Ice in the intertidal mudflats and sloughs in winter would be expected to force mysids, isopods, and amphipods into deeper delta platform and interdistributary habitats. Other mobile invertebrates may exhibit similar seasonality in their colonization of the delta nearshore zone.

In some instances, the intertidal areas provide important feeding grounds for juvenile chum salmon. This species is known in other Pacific Northwest and Alaskan estuaries to prey extensively on chironomids, harpacticoid copepods, and other small benthic organisms during the transitional period to marine life. The most visible and striking use of Yukon Delta inshore habitats is by waterfowl and shorebirds during summer and fall. Their energy demands for nesting, raising young, and migrating are met largely through invertebrate and plant standing crops found in the mudflats and associated wetlands. Pintails are an especially numerous occupant of the vegetated intertidal habitats in fall, feeding on the pondweed on interdistributary mudflats.

During late summer and early fall, decreased river discharge and prevailing onshore winds constrain the Yukon River's freshwater influence on delta habitats to the coast. Greater numbers of marine zooplankton are transported onto inner- and mid-delta platforms in the fall. It is possible that some of these species are residents of deeper subtidal channels which may not be subjected to complete freshening during summer months. This may reflect their occurrence in fish diets throughout the summer, although it seems more likely they are moved inshore during storms and coastal conditions promoting onshore advection.

The major portion of the Yukon River's outmigration of juvenile chinook and chum salmon occurs in late May and June. Peak outmigrations occur during periods of high river discharge and food availability. Chironomids and other aquatic drift are the major foods of smolts as they pass through lower river habitats. Although the foods are small, they are abundant, more easily captured than larger prey, and may provide an energetic advantage through their consumption in the riverine environment. Lower river, coastal slough, and other nearshore habitats are not used for rearing by juvenile salmon. Freshwater rearing must occur farther upstream, nearer to the redds.

Most juvenile salmon are carried in the river's flow far offshore of the delta front before they are able to sustain directed movements. Residence in this habitat is not known, although truer estuarine conditions exist 20–30 km offshore than closer inshore. Young salmon could be expected to remain in the delta front for an extended period or until becoming acclimated to seawater. Both chum and chinook salmon are large (compared to observed size of the species upon entry into estuaries elsewhere), which may allow them to take advantage of deeper water habitat beyond the delta front soon after the initial stages of their seaward migration. Growth normally associated with the first two weeks of estuarine residence by these smolts may occur in the river.

Comparatively few juvenile salmon are shunted into or appear to seek Yukon Delta coastal habitats. Those that are able to do so in early and midsummer could leave the river through the Middle and North mouths (areas of lesser flow), or arrive at the coast during periods when oceanographic or meteorological influences (e.g., high tides and onshore winds) allow movements of the fish into interdistributary tidal channels. Within these channels young salmon may be able to effectively utilize sloughs and other inshore areas during high tides. In this way the platform channels may provide a "marsh tidal channel" habitat for rearing salmon. As summer advances, late-migrating fish may be better able to negotiate downstream currents and to control their movements within coastal habitats.

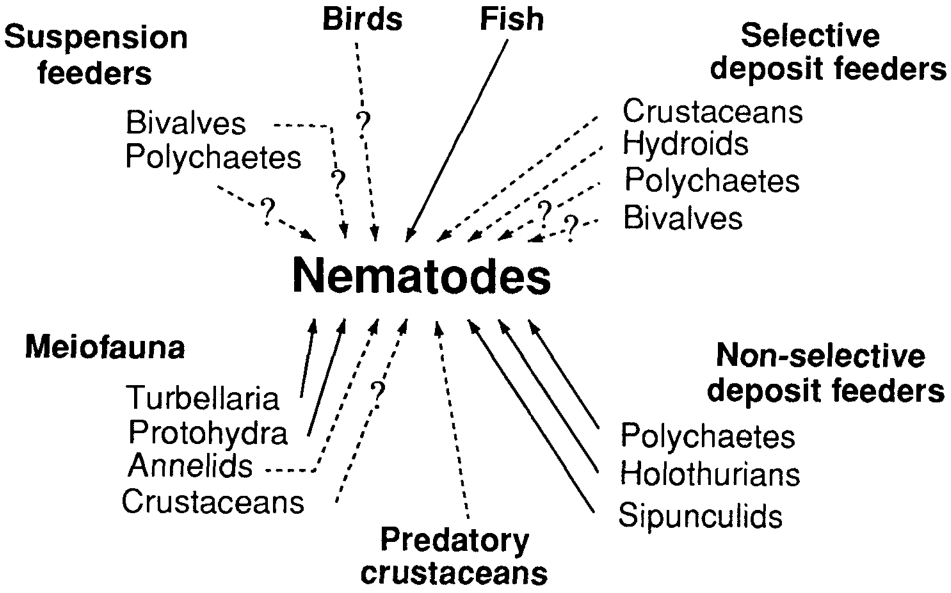

FIGURE 4.4—Summary of known and potential nematophagous organisms. Continuous lines from known nematovores, broken lines from probable nematovores, and queried lines from possible nematovores. (Adapted from Knox 1986.)

The small number of fish captured in tidal sloughs in two years of surveys suggests a lesser role for this habitat compared to other areas. In the Pacific Northwest and other parts of Alaska, shallow estuarine waters often provide a transition zone where young salmon can physiologically adapt to seawater before moving offshore. Offshore movements appear to be size-related and may result from density-dependent factors concerning food availability. Because of the high discharge rate of the Yukon River, the estuarine transition zone may be located seaward of the delta front, some 20–30 km offshore in Norton Sound. This location is supported by otolith analysis, which indicates waters near and beyond the delta may be serving as an offshore "estuary." Residence and use of offshore waters may be short (1 day to 2 weeks) for larger-sized chinook and coho juveniles and long (1 to several months) for species like pink and chum salmon, whose residence in the offshore estuarine zone may extend well into autumn.

The idea of an "offshore estuary" makes sense in light of the Yukon River's high flow rate. In addition to being an area where physiological adaptations for marine growth and survival take place, it is an area where diet changes from freshwater to inner shelf-derived organisms. Food availability will affect not only early marine survival but also the duration of residence in the offshore coastal environment. The location of the Yukon River plume at the delta front is not static, but shifts along the front in response to winds, tides, and discharge rates. Planktonic foods could be expected to be patchily distributed and in relatively low supply.

It is reasonable to expect patterns of zooplankton distribution and abundance in the nearshore waters of Norton Sound and off the Yukon Delta to be similar to those reported for other arctic waters (Neimark 1979; Cooney 1981; Merritt and Raymond 1983; Hameedi 1988) and subarctic waters (Coyle and Paul 1988). Small herbivorous grazers (body sizes less than 2 mm) such as copepods (*Pseudocalanus* spp., *Acartia clausi, Eurytemora* sp.) and cladocerans (*Evadne* sp. and *Podon* sp.) are expected dominants (Neimark 1979), with seasonal ranges in biomass of 7–12 g wet wt/m^2 (Cooney 1981). Zooplankton densities of 2,000–7,000 animals/m^3 have been reported in Kotzebue Sound (Merritt and Raymond 1983; Hameedi 1988). Hameedi (1988) observed that in the southern Chukchi Sea, small zooplankters, on the average, accounted for 89% of all zooplankton. Coyle and Paul (1988), studying zooplankton population and biomass in Auke Bay, southeastern Alaska, in 1985 to 1987, found minimum densities and biomass in April (2,000 animals/m^3 and 0.2 g/m^3) and maximum abundance in June (10,000–14,000 animals/m^3 and 1.5–2.0 g/m^3). *Pseudocalanus* spp. (individuals 0.6–1.5 mm long) made up 90% of the total copepod grazer biomass.

In laboratory feeding experiments, LeBrasseur et al. (1969) calculated that juvenile chum salmon require a concentration of 2,300 organisms/m^3 of the large copepod *Neocalanus plumchrus* to feed to satiation (equivalent to a biomass of 3.2 g wet wt/m^3). The fish required a *Microcalanus* concentration (individuals 0.4–1.5 mm long) of 9,300 animals/m^3 for the same effect (equivalent to a biomass of 0.56 g wet wt/m^3).

Collectively, these field and laboratory measurements demonstrate the importance of zooplankton patchiness on the foraging behavior of salmon. They may also explain the continued reliance on chironomids by salmon near the delta front where zooplankton may not be abundant. Beyond the delta front, cladocerans (*Evadne* sp. and *Podon* sp.) and larvaceans (in addition to the zoolankters previously mentioned) are likely to be important components of the zooplankton community as well as juvenile salmon diet. The cumulative effects of time and location of entry and size of fish upon arrival to delta front waters, coupled with availability of suitable foods and residence in this habitat, may be the greatest source of natural mortality at sea for Yukon River salmon populations. For instance, 90% of the juveniles captured in Shpanberg Strait in August 1986 were described as starving (Nishyama 1987, pers. commun. to E. Ozturgut during ISHTAR's Annual Program Review in St. Petersburg, Florida).

All but the very general aspects of other anadromous and marine fish use and life histories within the Yukon Delta estuary remain poorly known. Sheefish, whitefish, and cisco species exhibit complicated patterns of age- or size-dependent migrations into lower river habitats and coastal environs. Morphological differences within whitefish populations (e.g., numbers of gill rakers, shape of adult fish) are thought to exist and may reflect an adaptive divergence (Lavin and McPhail 1987) of individuals to the environment they are transported to as larvae (i.e., differing trophic environs). Most species appear to be intolerant of high salinity waters but are able to utilize brackish waters (0.5–20 ppt) and their epibenthic food resources. Juvenile coregonids apparently precede adults in their summer and autumn downstream migrations into deltaic slough and mudflat habitats. These areas offer a diversity of invertebrate foods encompassing marine, estuarine, and terrestrial origins and appear to be used most heavily in summer. Spawning takes place in upriver habitats (connected lakes), but these areas and whitefish spawning behaviors are very poorly described. Reproductive-age fish probably remain segregated from subadults for most of the summer. They are the first to retreat into fresh water, since spawning occurs in the fall. Subadults either winter somewhere in coastal habitats (possibly in interdistributary channels) or move upstream during fall and early winter to river wintering grounds. Few species remain resident in the slough, intertidal, or platform habitats during winter.

In spring and early summer the Yukon Delta coastal waters may be transited by migrant Pacific herring en route to coastal spawning grounds. No such spawning areas are known within the Yukon Delta. In much the same way, adult salmon move rapidly through lower river habitats to their upriver spawning grounds. Boreal smelt are common throughout the coastal waters of Norton Sound and are found in all Yukon Delta habitats. The coastal delta environment may provide an extremely important nursery for this species, as a preponderance of young fish were sampled. Small fish apparently congregate near the delta front during summer months and may provide an important food source to migrating salmon. Large, mature pond smelt were sampled regularly in the delta's coastal sloughs. These sloughs might provide spawning habitat for this species, the only fish suspected of spawning within the coastal nearshore. By midsummer, small marine fish, such as juvenile Arctic and saffron cod, begin to move into nearshore deltaic waters. Their occurrence coincides with arrivals of Arctic and starry flounders. As the season progresses, estuarine conditions permit these fish to make inshore excursions in search of epibenthic and small fish prey. As marine conditions intrude farther into the delta during the fall, larger marine predators, including adult saffron and Arctic cod, are commonly found in coastal platform habitats and occasionally closer inshore.

The Yukon Delta provides some of Alaska's best nesting habitat for geese, swans, and shorebirds. Millions of birds use the Yukon-Kuskokwim Delta wetlands for staging, nesting, and raising their young during the summer. These birds represent major exporters of wetland and mudflat energy reserves (derived from sedges, grasses, coastal invertebrates) in the form of stored fat for fall migrations. Over the course of the summer, bird use of coastal habitats for foraging and nesting results in a major energy pathway by which local resources (organic matter and nutrients) that are not stored as fats are metabolized, excreted, and redistributed across the delta. The precise nature of how these products are recycled in Yukon Delta habitats remains to be investigated.

The summertime use of coastal habitats by waterfowl has been well described with one notable exception, the use of tundra ponds and lakes. For many species these habitats provide additional sources of nutrients during their seasonal delta residence. The ponds often support fringing growths of grasses and sedges preferred by geese and swans and possibly planktonic forms (*Daphnia* and tadpole shrimp) fed on by shorebirds, such as phalaropes. Invertebrate food webs are simple in tundra lakes and ponds, where chironomid midges predominate. Large planktonic forms such as large cladocerans (*Daphnia* spp.), tadpole shrimp (notostracans), and fairy shrimp (anostracans) have been commonly reported in similar lentic habitats along the Beaufort Sea coast (Hobbie 1984). It is of interest that such fauna are characteristic only of temporary ponds in temperate regions. These lentic systems undergo periodic wetting–drying cycles, which essentially eliminate development of *in situ* predators, such as fish. Such elimination of higher predators is believed to enhance the development of these large plankters in such temporary aquatic habitats. The freezing of the ponds during the winter in arctic environments may act in a similar way to the wetting–drying cycles; however, the response of the predators in such aquatic systems remains to be pursued. Blackfish are the only fish found in this environment on the Yukon Delta. In larger lakes other species, such as ninespine stickleback or various coregonids, occur.

Recent OCSEAP studies have not focused on use of the Yukon Delta by mammals. Most information has come from other sources. In upriver habitats mink and beaver are abundant. The Arctic fox is a key predator on the eggs of nesting waterfowl across the Yukon–Kuskokwim Delta, and fox reproductive activity and success are thought to be linked to nesting waterfowl abundance in the preceding year. Of more interest to OCSEAP is the use of coastal deltaic habitats by seals, sea lions, and belukha whales. During the summer, these mammals can be expected to be relatively abundant during periods of fish abundance. Gray whales frequent Norton Sound during the summer en route to and from offshore feeding grounds in the Chirikof Basin and southern Chukchi Sea. Although gray whales have been observed in inner Norton Sound, they would be unlikely visitors to the coastal Yukon Delta. In winter the edge of the shorefast ice probably provides an important staging platform for seals and possibly the Pacific walrus, other species having moved farther south or west to winter in the southern and central Bering Sea.

Chapter 5

Future Research

The following discussion highlights some of the major information needs identified in this synthesis report; specifically, ecological information needed to improve the predictive capability of current risk assessment techniques. Other information needs have been identified in earlier sections of this report.

McDowell et al. (1987) have demonstrated that salt wedge intrusion into the lower Yukon River is an unlikely pathway (at least during the open water period) for contaminants such as spilled oil to enter delta habitats. Winter data are lacking to describe coastal processes, but it seems likely that nearshore habitats would be protected by (1) ice edge effects (reducing turbulence and mixing), (2) prevailing sea ice movements to the southwest, and (3) subsurface northwesterly transport of Norton Sound water masses (Zimmerman 1982). Storm surges remain the greatest potential mechanism for transporting water-borne contaminants onto the delta and into lower river habitats.

Predicting effects of OCS oil and gas development on resources and lifestyles of the Yukon Delta has been difficult in the past because of the limited understanding of coastal circulation. The acquisition of oceanographic data by McDowell et al. (1987) was designed to provide the variable measurements needed for fine-scale hydrographic modeling of the coastal (0- to 20-m depths) region. Numerical modeling of hypothetical trajectories (from offshore sites) in this nearshore is considered necessary only if (1) additional information is deemed necessary by the Minerals Management Service for assessing potential oil spill landfalls and possible nearshore impacts, or (2) more focused ecological research is conducted in key delta habitats. If a Yukon Delta modeling project is undertaken it should incorporate existing smear model algorithms, indices for retention of spilled oil in various substrate types, or other relevant information on sediment-oil and oil-ice interactions.

The OCSEAP research has resulted in the identification of several coastal habitats that are particularly important to Yukon Delta fish and bird populations. They include areas of intertidal mudflats and sloughs and associated wetland stands, and an offshore zone including and extending beyond the delta front. A third, less studied habitat type, the subtidal channel, is located between littoral and delta front portions of the Yukon Delta and may provide critical refuge (food, shelter, retention) for fish and invertebrate life forms. As such, these channels may extend the estuary, much like tidal channels in marshes, and provide seasonally important feeding areas for birds such as diving ducks. These subtidal channels are difficult to sample but because of their potential refuge value deserve additional attention.

The inshore delta habitats are subjected to extreme winter icing conditions that are inhospitable to most organisms. Accordingly, the Yukon Delta is like many other physically dominated coastal areas of the Arctic where littoral areas can only be seasonally colonized or invaded by most species, such as epibenthic crustaceans. The existing data suggest that amphipods and mysids (and in some instances isopods) are major prey of higher trophic levels. The importance of these animals in nearshore food webs in summer and fall has been observed in other arctic ecosystems. In addition to winter-imposed living constraints, some portions of the intertidal zone can only be utilized by estuarine fish and crustacean species during certain tidal stages (e.g., flooding). Because of these habitat restrictions, the complex of delta platform ice gouge channels may offer daily retreat, if not year-round refuge, to many resident species. Their importance to anadromous fish has been discussed in detail.

Additional information is needed to describe the ecology of Yukon Delta mudflats and sloughs. They are of tremendous importance to waterbirds in fall, and as a transitional environment between terrestrial, riverine, and aquatic zones, of unknown (but suspected high) ecological value to other delta animals (local food webs). Quantitative evaluations (including rate information) of the (1) composition and origins of *particulate detritus* and chemical constituency of *dissolved nutrients* being imported into these zones; (2) utilization of organic material and nutrients by the invertebrate fauna and emergent plants associated with major habitats; and (3) physical and biological exportation of materials to adjacent coastal habitats are needed to understand actual habitat functioning in the

Yukon Delta. Particular research emphasis is needed on the processing of various detrital particles and nutrient cycling within various components of the invertebrate fauna and their transfer to shorebirds and fish. Future studies should be field- and laboratory-oriented, providing comprehensive evaluations of community structure and function not only within intertidal and slough habitats, but in surrounding areas or other deltaic habitats contributing to their productivity. Physical and biological factors influencing production within the meiofaunal community and its nematode component should be examined in the context of local food webs. This information would provide the basis for testable hypotheses regarding variability in habitat use and animal abundance in the Yukon Delta. This approach provides an evaluation of habitat use at various spatial and temporal resolutions needed if predictive ecosystem modeling is a goal of research. The chemical interactions within and between infaunal and epifaunal mudflat communities (i.e., examination of their roles in nutrient spiraling and population productivities) and the role of aquatic insects throughout delta habitats would be primary research concerns.

Delta front and inner shelf waters of Norton Sound may be functioning in the capacity of an "offshore estuary" for juvenile salmon. This reflects the Yukon River's freshwater influence on the nearshore environment. Estuarine residence among Pacific salmon is known to vary by species but is considered a critical phase in early marine life. The duration of estuarine residence may be related to size of fish or reflect a density-dependent mechanism. In either case it seems to be related to food availability and acquisition by young salmon. Two years of survey data indicate that chironomids dominate the diet of young salmon in the Yukon Delta. Their diet must change from one composed principally of chironomids (midges) to planktonic inner shelf organisms during the estuarine transition period. For more piscivorous and larger-sized migrants, such as chinook and coho smolts, sand lance and small smelt-like fishes (identified in abundance near the delta front) probably assume immediate dietary importance. For other species, copepods, euphausiids, cladocerans, and larvaceans are probably important foods. Such habits need to be verified through field studies. Previous research on chum salmon in Puget Sound (Simenstad and Salo 1980) has shown that fry feed heavily on epibenthic harpacticoid copepods and gammarid amphipods soon after entry into the estuary. Within about two weeks the fish attain sufficient size to use deeper waters and feed on larger nektonic prey (calanoid copepods, hyperiid amphipods, and larvaceans). In the Yukon Delta, most chum salmon fry (and other salmon species) are carried 20–30 km offshore in Yukon River currents to the delta front. The juveniles are large, and must be able to capture pelagic foods (large zooplankton and fish larvae) after a brief acclimation period.

Offshore oil and gas development in Norton Sound may overlap areas of estuarine transition for Yukon River salmon. Additional exploratory research is needed to examine juvenile residency and use of nearshore waters near and beyond the delta front. This research could also be directed at resolving other issues pertaining to seaward migration of Pacific salmon, residency of populations in OCS leasing areas, and resources at risk. Straty (1981) suggested that Yukon River emigrants probably move in a southwesterly direction upon leaving the river. However, a *northwesterly or westerly* migration route would possibly lead salmon to more productive feeding grounds in the central and northern portions of the Bering Sea on an earlier schedule than they could reach similar pelagic habitats by other pathways. There are obvious growth and survival advantages to salmon by such a migration. The location of the Yukon River plume relative to the coast is dynamic and may influence the direction of seaward migration. Stock identification objectives could easily be incorporated into future programs to provide additional information on stock timing and rate of seaward migrations.

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