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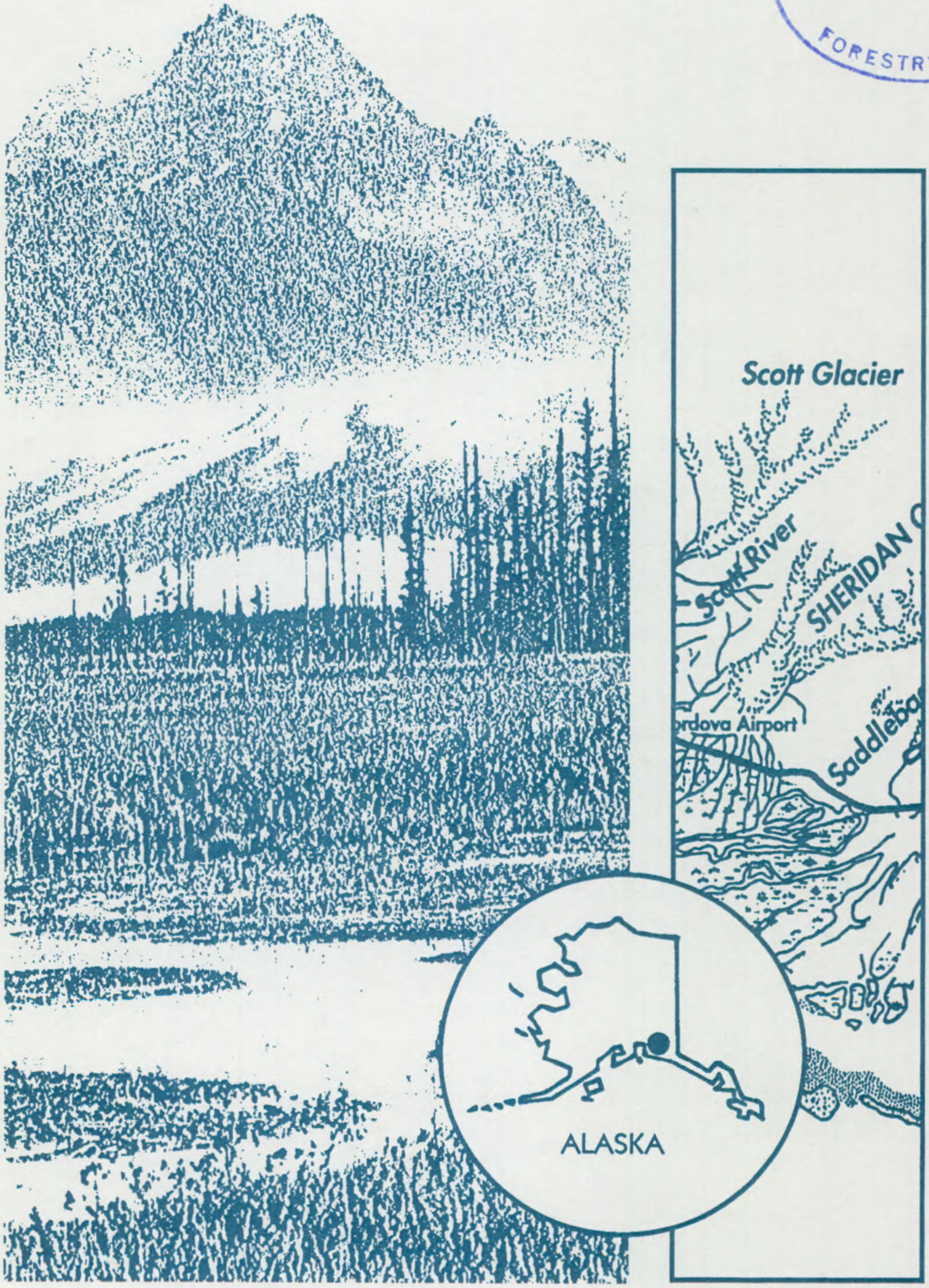

The Copper River Delta Pulse Study: An Interdisciplinary Survey of the Aquatic Habitats

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Abstract

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In July 1987, a 2-week synoptic survey was conducted on the wetlands of the Copper River Delta by an interdisciplinary team of scientists. Disciplines included geomorphology, limnology—water chemistry and nutrients, plankton and macroinvertebrates, anadromous fish populations, and wetland plant ecology. The purpose of this report is to present a summary of the findings of each group, preliminary conclusions, and recommendations for further research. The results are limited in scope due to the limited observation time and the single point in the year—midsummer. Because all observations were done concurrently at similar sites, the results are linked in time and place. Trends in productivity across the wetlands appear in the results. High rates of methane production indicated higher levels of production in ponds and beaver sloughs than expected as well as anaerobic decomposition processes in the ponds. Greater diversity in both phytoplankton and zooplankton species were observed in the ponds and sloughs than in glacial streams. Beaver ponds, sloughs and woodland streams were found to support the highest densities of juvenile coho salmon. Sockeye salmon were observed in the wetland and intertidal sloughs. The results indicated that complex interactions occur among geomorphology, plant succession, nutrient cycles, and hydrologic processes affecting biological production. Research should address ecosystem processes, linkages throughout the trophic structure, and successional stages within the wetlands.

Keywords: Wetlands, aquatic habitat, Copper River Delta, salmonid habitat, wetlands research, water chemistry, aquatic biology.

Contents

Introduction

Mason D. Bryant[1]

The Copper River Delta is a complex ecosystem that includes a diverse set of aquatic habitats within its 283 000 hectares. These aquatic habitats produce significant numbers of sockeye salmon (*Oncorhynchus nerka*) and coho salmon (*O. kisutch*) (Randall and others 1986) as well as Dolly Varden char (*Salvelinus malma*) and cutthroat trout (*O. clarki*). Although the Alaska Department of Fish and Game (ADF&G) has collected catch and escapement data for the commercially important species of the Copper River and the Copper River Delta wetlands, no research has been conducted to determine the factors controlling the biological productivity of the aquatic habitat of the wetlands or of the abundance and distribution of juvenile salmonids in the wetlands.

Scope and Objectives

We conducted a synoptic survey to establish a data base for the Copper River Delta, to identify future research needs, and to provide a starting point for management of the aquatic habitat for juvenile salmonids. The survey examined geomorphic, hydrologic, chemical, and vegetative characteristics of aquatic habitats and their planktonic, macroinvertebrate, and salmonid assemblages to obtain a "whole ecosystem" perspective of the delta. The objectives were to:

1. Define the primary geomorphic factors influencing the aquatic habitat structure.

2. Synoptically survey important chemical constituents that could influence productivity of the aquatic habitats.

3. Describe major phytoplankton, zooplankton, and invertebrate communities in ponds, streams, and distributary channels.

4. Identify and describe major aquatic habitats used by juvenile salmonids in the Copper River Delta.

5. Determine species distribution and relative abundance of juvenile salmonids in major aquatic habitat types in the delta.

6. Identify and describe major plant associations and their interaction with aquatic habitat.

Study Area

The boundaries of the study area were the Heney Range on the west and the Ragged Mountains to the east of the Copper River flood plain. Longitudinally, sites extended from the base of the Scott and Sheridan glaciers to the intertidal mud flats and offshore islands (fig. 1). Habitat units were differentiated by large-scale geomorphic and hydrographic units (table 1). Fluvial units were divided into glacial and clearwater riverine systems that included forest streams, braided channels, interbasin slough and channels, and distributary channels; and lacustrine systems that included lakes, beaver ponds, and slough or "perch" ponds. Each is easily identified and has distinct physical characteristics.

Most of the habitats surveyed in this study are wetlands, where the water table is at or above the surface throughout the year and the land is periodically flooded (Cowardin and

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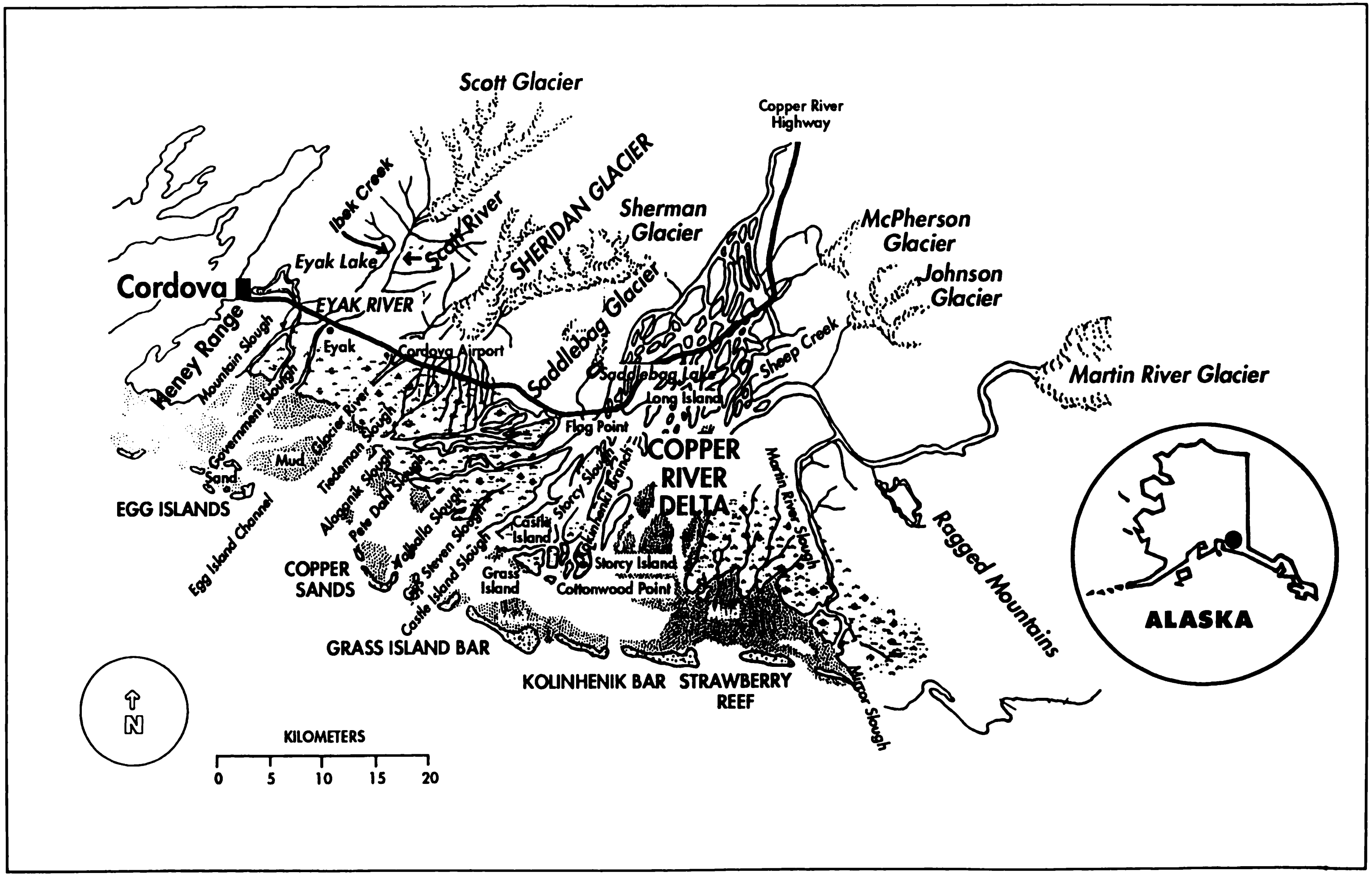

Figure 1—The Copper River Delta study area.

Table 1—Location of study sites and habitat types

Location and area	Habitat Type
Eyak River:	
Mountain Slough	Distributary slough channel (glacial); clearwater "headwall" tributary to mountain slough
Center Slough	Interbasin slough channel; beaver pond system in interbasin slough channel
Government Slough	Distributary slough channel (glacial)
Alaganik Slough:	
Alaganik Slough and 18-Mile streams	Distributary slough channel system; "upland" forest stream with beaver pond and clearwater stream riffles and glides
25-Mile streams	"Spring fed" forest streams; lowland beaver ponds
Martin River Slough	Clearwater distributary slough channels; clearwater streams

others 1979). All the land about 4.8 kilometers south of the Copper River Highway (fig. 1), with the exception of a few islands of Sitka spruce (*Picea sitchensis* (Bong.) Carr.), fall into this category. North of the highway, glacial outwash piedmonts are the primary wetland habitat component (Thilenius 1990). Thilenius reports a continuum of wetland vegetation from sea level to more than 30 meters above sea level.

Thilenius (1990) classifies the lowland regions of the Copper River Delta into several major physiographic areas. Progressing from the open ocean to the fronts of the glaciers, these are ocean beaches, offshore barrier sand spits and islands, estuary, old marsh, and glacial outwash piedmont. The ocean beaches and the offshore barrier islands are primarily sand and are the direct interface between the open ocean and land. The estuary, composed primarily of fine sediments, is divided into subtidal and intertidal surfaces. The intertidal area includes the wetlands elevated from subtidal to intertidal after the 1964 earthquake, referred to as the "new marsh" by Thilenius (1990). The new marsh has several small-scale geomorphic features such as sediment islands formed by patches of *Carex* (sp.) and dentritic channels. The old marsh is part of the estuary that was intertidal before the area was uplifted during the 1964 earthquake and includes the foreshore levee with a wave-cut terrace on the seaward edge, river, distributary slough channels, interlevee basins and ponds, and interbasin sloughs (fig. 2). Distributary slough channels are branches of main river systems flowing through the delta, such as the Alaganik Slough (fig. 2). Interbasin slough channels drain the wetlands; they usually are spiral and may wind around a perch pond. Distributary slough channels are often highly glacial, whereas interbasin slough channels are usually clearwater. The levees support mesic and semihydric woody and plant communities, whereas the interlevee basins contain marshes and perch ponds. The latter are small ponds perched on the wetlands with water levels generally above the water level of the channels. The glacial outwash piedmont is the most inland and is composed primarily of mixed—cobble to sand size—sediments. Braided channels are associated with the glacial outwash.

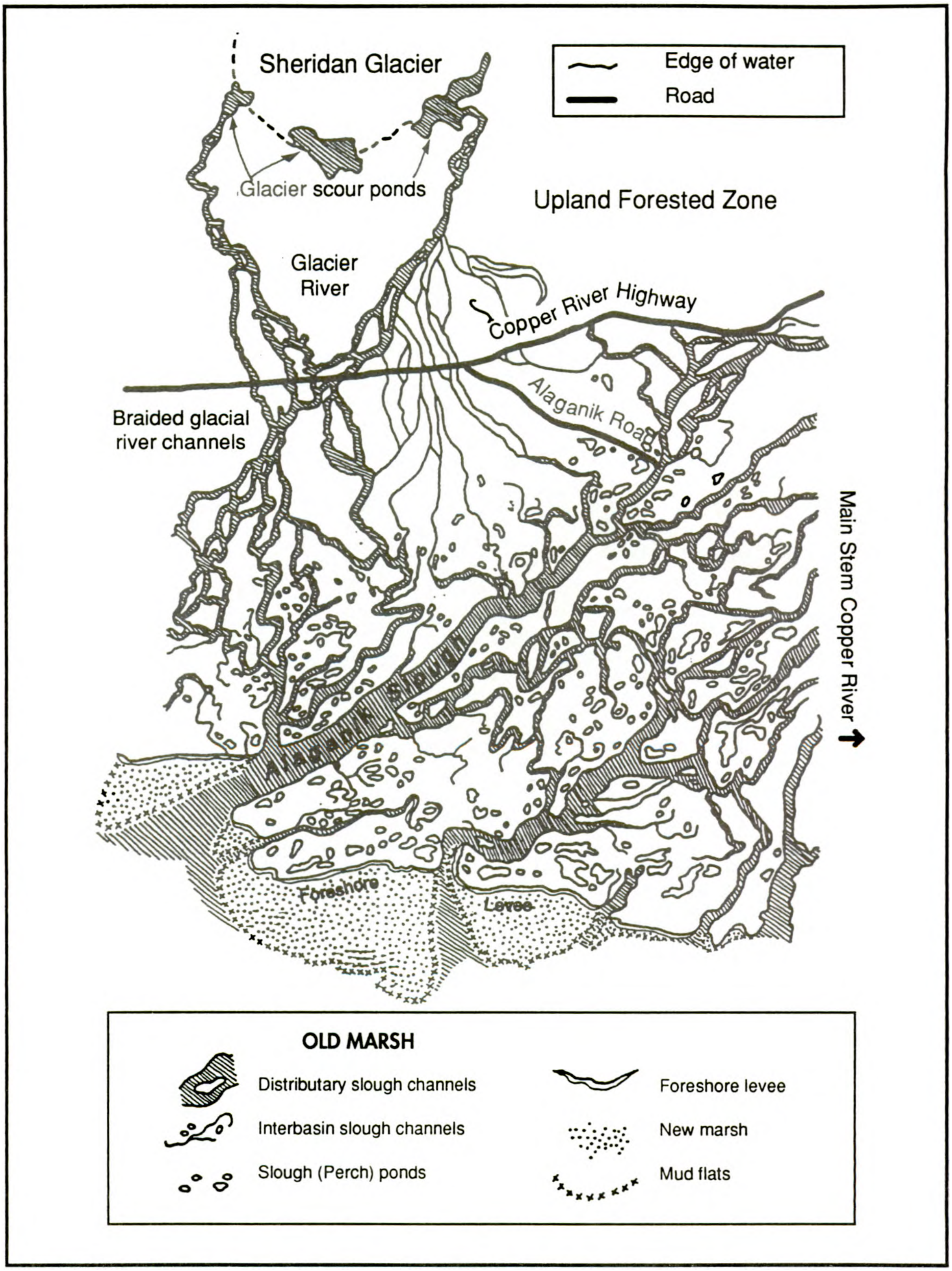

Figure 2—Section of the Copper River Delta wetlands showing primary terrain features.

The glacial riverine systems characterized by Ibek Creek, Eyak and Glacier Rivers, and the main stem of the Copper River are fed by glacial meltwater and carry large amounts of suspended fine sediment and coarse alluvial bedload. Flows fluctuate with the rate of glacial melting and rainfall. The channel morphology changes from braided channels near their origin at the face of the glaciers to incised channels downstream in tidally influenced surfaces. The main channels often form distributary slough channels, such as the Alaganik Slough from the Copper River (fig. 2).

The interbasin slough channels that meander through the wetlands are fed by precipitation and possibly by subsurface flow. Distributary slough channels and interbasin slough channels are bounded by levees of various heights. Further inland are clearwater streams fed by precipitation and snow melt. These streams traverse forested terrain and are tributaries to larger rivers and distributary slough channels, such as the Glacier River or Alaganik Slough.

Lacustrine habitat types in the wetlands are perch ponds and ponds formed by beaver dams on interbasin slough channels. Beaver ponds are common on many of the interbasin slough channels and have an important effect in flow direction and channel morphology. The interbasin slough channels are commonly long and deep. The perched ponds are fresh water, shallow, and apparently eutrophic. They occupy over one-third of the area of the interlevee basin of the old marsh (Thilenius 1990). Lakes and ponds in the uplands, such as scour ponds at the toes of glaciers or kettle ponds, usually are associated with glacial activity. Beaver ponds also occur in some of the forested streams. The geology, climate, physiography, and vegetation of the Copper River Delta are reviewed and described by Reimnitz (1966) and Thilenius (1990). Thilenius also reviews and describes the effects of weather patterns and tidal cycles on the delta and successional changes in vegetation patterns within the wetlands.

Study sites were located in two drainage basins west of the Copper River—the Eyak River and the Alaganik Slough—and one east of the river—the Martin River Slough (fig. 1). The main channel of the Copper River was not sampled extensively. Eyak River is heavily influenced by glacial runoff. The river originates in Eyak Lake, which acts as a settling basin for glacial runoff from the Shepherd Glacier that drains into Power Creek. The lower part of the river receives glacial runoff from the Scott Glacier through Lydic Slough. Alaganik Slough is less influenced by glacial runoff. Until 1987, it was the westernmost distributary channel of the Copper River and was highly glacial. After 1987, the inlet from the Copper River was isolated as the Copper River migrated eastward. Alaganik Slough currently is fed by the McKinley Lake drainage and receives some glacial input from the Saddlebag Glacier, which drains into McKinley Lake. Both systems have numerous interbasin slough channels and tributaries that drain the wetlands and the upslope terrain of the mountains. The Martin River Slough is a clearwater system and has no direct glacial influence. Although the Martin River Slough was at one time the main channel of the Martin River, the channel now is blocked and the Martin River flows into the eastern edge of the Copper River Delta. Beaver ponds are common in the sloughs draining into the Eyak Basin and the Alaganik Slough but are less common in the Martin River Slough drainage.

Preliminary selection of sample sites was done during the first week of June 1987. Intensive sampling at all sites was conducted from 20 to 31 July 1987. Most samples and measurements were obtained at the same or nearby sites, although not necessarily concurrently. The primary objective of the sampling design was to obtain data at a single point in the season over a wide geographic area of the delta.

Geomorphology

L. Benda, T. Lisle, and K. Sullivan[1]

Introduction

The survey of the geomorphology of the Copper River Delta included (1) morphology and distribution of sloughs and ponds, (2) particle-size analysis of sediments in channels, and (3) morphology of channels. All three directly influence the distribution of wildlife and fish habitats across the delta and on vegetation succession. We propose a preliminary working hypothesis for the development of channel and pond morphology on the delta.

Morphology and Distribution of Channels and Ponds

Distribution of geomorphic environments—The Copper River Delta has actively prograded since the end of the Pleistocene, about 10,000 to 13,000 years before present. The delta advances or grows seaward by a combination of gradual sedimentation (of the Continental Shelf) and abrupt tectonic uplift; for example, portions of the delta were uplifted 1 to 2 meters as a result of the 1964 earthquake. The morphology of the delta (channels, sloughs, and ponds) changes along a transect from the Chugach Mountains to the Gulf of Alaska. The change in surface and channel morphology is primarily the result of sorting of particle sizes typical of deltaic environments, vegetation, and tidal forces.

Braided, dendritic channels form in the glacial outwash composed of coarser substrates (sediments greater than sand size). This pattern extends from the glacial fronts towards the lower portions of the delta, such as the Glacier River (fig. 2). Few ponds are found in this area, and those are small and may be atrophied. Heading seaward toward the lower marsh, channels bifurcate into deep distributaries such as the Scott and Eyak Rivers. The distributary slough channels are formed in banks composed of silt and have low width-to-depth ratios (see section on "Channel Morphology," below). In addition, the lower marsh area of the delta is dominated by numerous ponds located between distributary slough channels, such as those between Alaganik and Pete Dahl Sloughs (see fig. 1). The tidal mud-flat of the lower end of the marsh seaward of the foreshore levee is intertidal and periodically flooded. Flow through the distributary channel network creates open and submerged channels that drain the mudflats at high tide. Examples of these types of networks are found between Eyak River and the mainstem of the Copper River (fig. 1).

The channel and pond environments have developed gradually in the seaward margin of the delta as the result of sedimentation; however, both vertical accretion and vegetation succession result in loss of ponds and interbasin slough channels in the upper reaches of the delta. The transect from the mountains to the gulf transverses surface morphology that is older near the mountains and younger toward the gulf.

Rates of sedimentation on the delta—The rate of sediment accumulation on the delta influences many aspects of the geomorphology of the ponds and channels and certain aspects of plant succession. The rates of sedimentation on the delta were estimated by measuring the sediment thickness above buried forest layers that were carbon-14 dated by Reimnitz (1966). Two distinct buried organic layers consisting of remains of trees within large portions of the lower delta, an area now covered by tidally influenced marsh, were dated at 900 and 1,700 years (Reimnitz 1966). Measurements of sediment thicknesses

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above these layers indicated that the accretion rate of sediment on the delta averages 4 millimeters per year (range 2.8 to 4.6 millimeters per year). Measurements of sediment accumulation on newly uplifted areas of the delta (the new marsh) were 16 millimeters per year, thereby indicating that sedimentation rates are not constant over time and probably depend on the elevation of the delta surface relative to sea level. These estimated sedimentation rates on the delta provided a basis for developing a preliminary, working hypothesis on channel and pond morphology within the delta.

Levees and the formation of ponds—From our field measurements and observations, we propose the following preliminary hypothesis for the development and morphology of interbasin slough channels and ponds, an environment dominating the lower portion of the delta. Ponds and interbasin slough channels in the delta begin to develop as gradual sediment deposition raises the elevation in the intertidal area. Tidal flooding causes a dendritic channel network to form between the larger distributary slough channels (fig. 3A). This is the present state of channel development on the new marsh.

Tidal flooding over the banks of the sloughs results in greater sediment deposition adjacent to channels than elsewhere, because of the steep negative velocity gradients and vegetation that traps sediment. Deposition of fine sediment immediately adjacent to channels creates levees. Organic matter from plants and their root masses also contributes to the process of levee establishment and growth. The development of levees adjacent to the major interbasin slough channels over long periods creates closed basins (fig. 3B). Precipitation and tidal inundation fill these basins with water and create large ponds. Surveys across major distributary slough channels to pond centers gave mature levee heights (see fig. 4) ranging from 0.3 to 0.5 meter (table 2) and averaging 0.43 meter. The widths of levees ranged from 21 to 56 meters (fig. 4, table 2). The difference in elevation between levee crests and pond bottoms (fig. 4) above carbon-14-dated buried forest layers indicated that the average difference in rate of sediment accretion giving rise to levees was about 0.6 millimeter per year.

Formation of interbasin slough channels and fragmentation of ponds—Because the elevation of the water surface in the ponds is several meters above the elevation of the water in adjacent interbasin and distributary slough channels, an energy gradient exists that promotes the formation of drainage channels leading into the pond-filled depressions. The small interbasin slough channels may begin either with a breach at a low or weak point in the levee system or by occupying a portion of the remnant channel network that initially developed on the mudflats. They probably developed after the establishment of large, relatively permanent ponds on the delta. The interbasin slough channels migrate over time into the interior of the pond-filled depression (fig. 3C). The interbasin slough channels are tributaries to the major distributary slough channels and are subjected to tidal flooding. Levees are formed as sediment is deposited on the banks when they are inundated by tidal flooding.

The orientation of the interbasin slough channels is controlled by the microtopography of the closed depressions and not by the slope of the delta, that influences the orientation and patterns of the larger, distributary channels. The interbasin slough channels migrate headward and avoid areas of high relief such as levees. The process of avoiding levees will often cause the interbasin slough channels to migrate until they encounter their own levees, which creates a deranged and spiral pattern (fig. 3C).

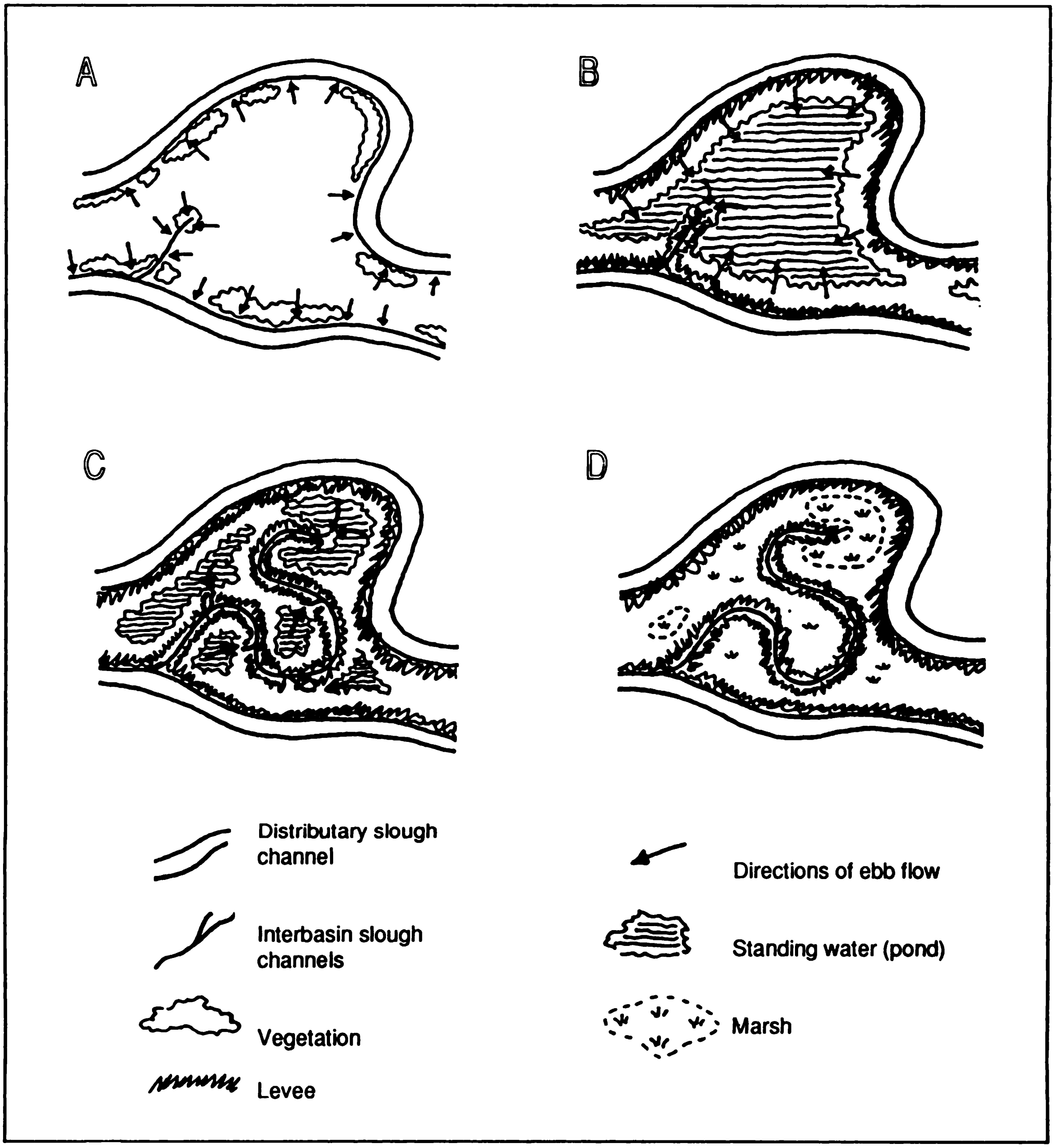

Figure 3—Proposed evolution of slough and pond develpment.

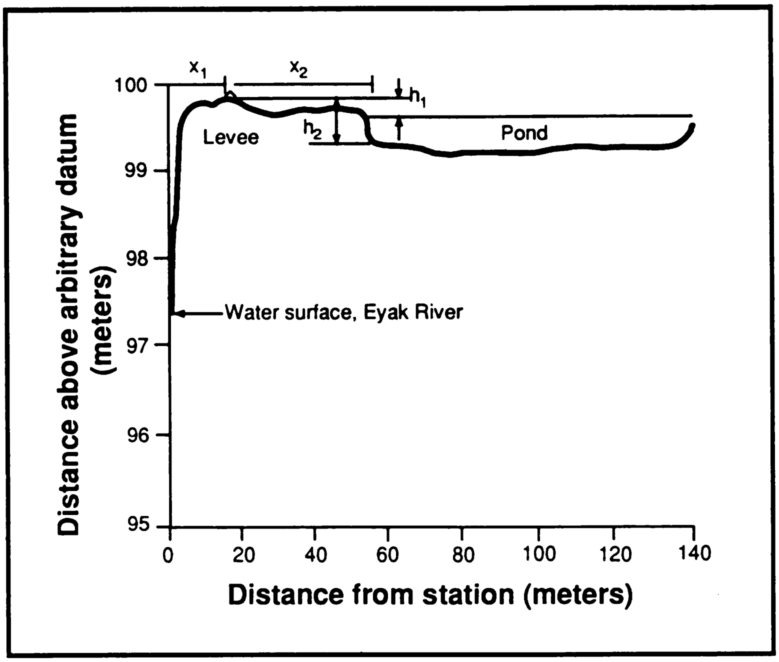

Figure 4—Cross-section of pond and levee system on the lower Eyak River (cross reference LE1, 21 July 1987).

Table 2—Levee dimensions[a]

Location	h_2[b]	x_1[c]	x_2[d]	x_1+x_2 Total levee width	Pond Present
			Meters		
Eyak River	0.46	12.7	39.5	52	Yes
	.49	10.4	46	56	Yes
	.46	20	30	50	Yes
Circle Slough	.55	12	25	37	Yes
	.30	14	34	48	Yes
	.31	9	25	34	Yes
	.32	14	7	21	Yes
	.08	N/A	—	—	No
Elsner River	.52	24	21	45	Yes
Martin River Slough	.48	—	—	41	Yes
	.15	—	—	—	No
Average with pond	.43			44	
Average without pond	.15			—	

[a] See figure 4 for explanation of variables
[b] Height of levee (from top of levee to bottom of the pond)
[c] Width from levee crest to edge of slough channel
[d] Width from levee crest to edge of pool

The headward migration of interbasin slough channels into closed basins fragments larger ponds into smaller ponds (fig. 3, B and C). The fragmentation of large ponds into small ponds continues until the remaining area is too small to support either a pond or further channel migration (fig. 3D). Under this mechanism, the largest ponds are the youngest and they will be found along active margins (that is, large distributaries and delta margins), and smaller ponds will be older and likely found further away from active edges. If this hypothesis holds, then pond size will be inversely correlated with density of interbasin slough channels, and pond density will be positively correlated with density of interbasin slough channels. We have not tested these relations statistically, but we have observed them in the field and on maps and aerial photos.

Levees of interbasin slough channels decrease in height with distance upstream within a pond-filled depression (fig. 3C). For example, levee heights along two interbasin slough channels decreased from about 0.3 to 0.4 meter near their mouths to 0.15 to 0.08 meter, respectively, at their channel heads. Ponds did not occur near channel heads having reduced levee heights. The decrease in height of levees can be accounted for by the relatively young age of channel heads (that is, limited time for levee development), because overbank flows at these locations would occur less often because of the relatively higher elevations of the channel heads. Based on these surveys, we estimate that a levee height between 0.1 to 0.2 meter is necessary to support a perennial pond.

Time scale of pond development—Sedimentation rates allowed us to estimate the time necessary to form ponds in the absence of tectonic uplift or subsidence. Based on our calculations of the difference between the rate of sediment accretion on levees compared to the rate in the ponds of 0.06 centimeter per year and the estimated critical levee height to maintain ponds between 0.1 to 0.2 meter, the time necessary for pond development will range between about 1.5 and 3.5 centuries. Additional time will be needed for development of interbasin slough channels and the subsequent fragmentation of larger ponds into smaller ponds; for example, levees were not detected on the new marsh during our field surveys. According to our estimates of rates of levee development, levees formed on the new marsh since the 1964 earthquake would only be 1.4 centimeters high, an elevation not detectable with our surveying techniques.

Pond evolution and implication for plant succession—As the Copper River Delta gradually progrades seaward or is episodically uplifted by regional tectonics, the pond and interbasin slough channel environment (fig. 3, A to C) becomes laterally and vertically isolated from the tidal influences. This will decrease rates of sedimentation. As a result, levee building will diminish, and as organic matter accumulates in the pond, the pond will fill. Subsequently the difference in elevation between pond bottom and levee crest will be eliminated. The reduction of levees in this manner will promote a vegetative succession in the depressions as the ponds dry out. The ponds will atrophy and eventually disappear. Surveys of atrophied ponds (no standing water) southwest of the airport at Cordova revealed that accumulation of root masses of marsh grasses and forbs in pond bottoms had eliminated the difference in elevation between the levee crest and pond bottom. Removal of this vegetative mat revealed that the difference in elevation was 0.3 meter. This depth is sufficient to support a pond in the more seaward portions of the delta.

We envision that sedges and forbs will be the primary vegetation in newly formed mature ponds and interbasin slough channel environments, but as the rate of sediment accretion on the levees decreases, the herbaceous species will give way to more mesic species, such as woody shrubs. These species may be replaced by spruce forests as the sites continue to dry. This sequence of pond evolution and plant succession will occur over several centuries and could become much more complicated (in time and space) if disturbances such as tectonic uplift or subsidence or channel avulsion were to occur. This succession of surface morphology and of vegetation will have significant influences on the types and distribution of wildlife and fish habitats on the Copper River Delta.

Hypotheses for pond and channel development and distribution—The proposed hypotheses for development of the pond and interbasin slough channel systems allow us to define certain relations for the distribution of physical environments across the Copper River Delta. We have observed most of these patterns in the field or on maps and photos but have not tested them statistically.

1. Large ponds are divided into smaller ponds with a concurrent increase in the density of interbasin slough channels. There should be relations between pond size and number and the density of interbasin slough channels.

2. The youngest ponds will be the largest. The youngest and largest ponds will be associated with active, youthful margins (that is, delta and large distributary channel margins). Smaller ponds may occur on older surfaces isolated from zones of active tidal and riverine sedimentation.

3. Within any particular pond-filled depression, the ponds and channels farthest upstream will be the youngest. The levees at the heads of interbasin slough channels will be the youngest and hence the smallest.

4. There will be a characteristic minimum spacing between any two interbasin slough channels, or between them and distributary slough channels, because migrating interbasin slough channels will avoid levees. This should apply if an interbasin slough channel either spirals back onto itself or encounters a distributary slough channel. The characteristic minimum spacing will be on the order of 50 meters, the average width of a mature levee (fig. 4, table 2).

5. There will be limits to pond size, pond density, and drainage density, because of the loss of contributing area with headward migration into closed basins.

6. Ponds will be the oldest, and may be atrophied, with increasing distance from active margins. This age gradient of ponds and interbasin slough channels may influence certain aspects of plant succession on the delta. Marsh grasses and forbs will dominate youthful and mature pond and interbasin slough channel systems, but with increasing age and hence distance away from active margins, grasses will be joined by woody shrubs, and eventually when ponds sufficiently dry out and atrophy, spruce forests may invade and dominate the surface. This sequence can be made more complex by disturbances such as tectonic uplift or subsidence or channel avulsion.

The hypotheses put forth for pond and channel development are supported by our field measurements and observations but are preliminary working hypotheses. They present a foundation for viewing certain aspects of the geomorphic and biological dynamics of the Copper River Delta, thereby providing a preliminary framework for conducting further studies.

Analysis of Particle Size in Channels

Fluvial systems in the Copper River Delta, as in other areas of active mountain building and glaciation, can be characterized by rapid decreases in channel gradients and size of bed material over short distances from mountain fronts and glacier termini to outwash plains and intertidal channels. Bed material size, measured over the heads of bars in outwash channels from Scott and Sherman Glaciers, decreases from gravel and cobbles downstream from the terminus to sand and medium pebbles at the highway to sand in the tidal zone (fig. 5).

Slope correlates well with median grain size (fig. 5), thereby suggesting that grain size could be predicted from stream gradients measured on topographic maps. If a relation of slope to grain size proves useful for recognizing spawning habitat, its application to other areas will require calibrating relations by geology and fluvial geomorphology. Bedrock in this area appears to be mostly fractured, but competent, sandstone and shale. The predominant roughness elements in outwash channels are bed material, sand bed forms, and bars. Roughness elements in channels within forest zones also include large woody debris and more resistant, irregular banks. The additional roughness in forest streams can be expected to cause smaller grain size for a given slope than that in outwash channels. Meadowbrook Creek, located east of Sherman Glacier, is an example of a forest stream that has smaller bed surface material than predicted by the rest of the data from outwash channels.

Outwash channels appeared to offer little spawning habitat. These channels have abundant gravel only near the glacier termini where they are unstable. Water is cold and laden with suspended sediment. Forest streams such as Meadowbrook Creek and Salmon Creek (east of the Sherman Glacier) appear to offer excellent spawning and rearing habitat, because they contain relatively stable bar-pool sequences, abundant gravel, and large woody debris.

Channel Morphology

Channel morphology showed a progressive change from glacier termini to tidal distributaries. This suggests a response to the increase in the concentration of suspended sediment and sand relative to gravel. At the glacial termini, channels are wide and shallow—width:depth ratios of flow exceed 50:1—and have poorly defined banks created by margins on bars of coarse bed material. Banks of silt and sand capable of supporting willows and alder occur where sand becomes the predominant bed material and the major outwash flow shifts away from portions of the outwash plain. Gravel and cobble channels in forest streams are narrower and have much better defined banks than those in the marsh wetlands.

Scott and Sherman Glaciers flow into a series of outwash channels that appeared to be flowing at or above bankfull stage during our survey in July 1987; other channels of similar size without meltwater from the glaciers flowed at a much reduced flow. This suggested that the flow regime for a particular channel in the braided systems depends on channel shifting and capturing of outwash flow. Because of the seasonably warm weather causing glacier melt, runoff was high. Just downstream from the highway, dominant channels deposit large volumes of sand over the bank. Channels in this zone contain dunes and linguiform and longitudinal bars that seem to shift frequently within sod-reinforced banks. Further downstream (approaching the tidal zone), channel width decreases and becomes more uniform, presumably as sand bedload declines relative to suspended sediment.

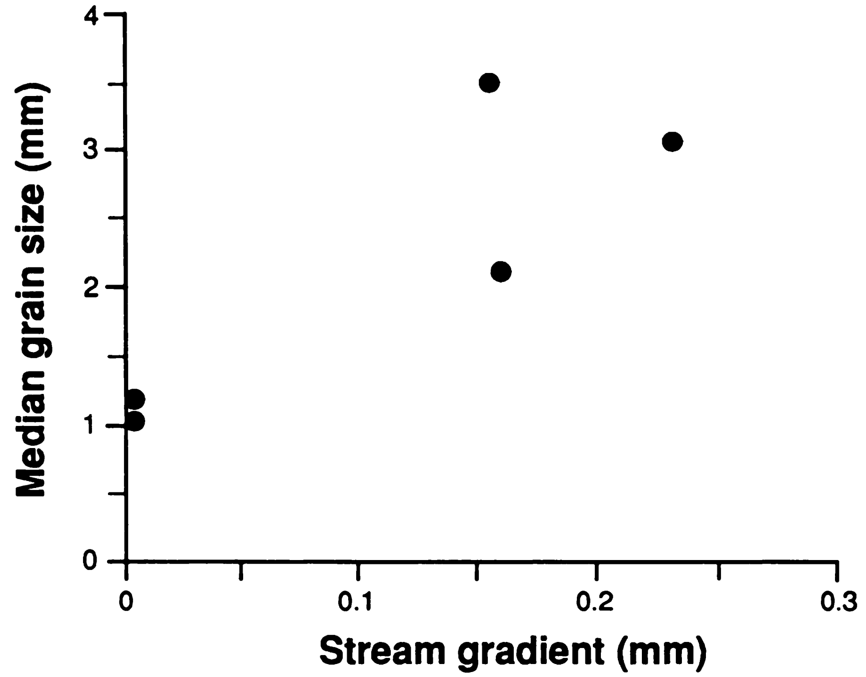

Figure 5—Correlation between slope gradient and grain size of channel substrates in the Copper River Delta wetlands.

Dissolved Gases, Nutrients, and Water Chemistry

R.C. Wissmar, A.H. Devol, and M.D. Lilley [1]

A comprehensive synoptic survey was made of the distribution and concentration of dissolved chemical constituents in aquatic habitats of the Copper River Delta in July 1987. The overall objective was to make a preliminary identification of nutrients and associated inorganic and organic chemical conditions that influence or reflect the productivity of aquatic habitats in the delta. The principal habitats surveyed included streams, rivers, sloughs, and marsh ponds (table 1). The major delta regions include the Eyak River, the Alaganik Slough, the main channel of the Copper River, and the Martin River Slough (fig. 1). Measurements were made of dissolved chemical constituents; for example, cations and anions, major nutrients, trace gases, oxygen, carbon dioxide, pH, alkalinity, and dissolved organic carbon (DOC) (table 3).

An electric water pump was used to collect water samples. Methane samples were placed in 125-cubic-centimeter tubular Pyrex flasks with Teflon stopcocks.[2] Flasks were flushed to exclude air bubbles and poisoned with 10 milligrams per liter $HgCl_2$. Methane was stripped from the water and analyzed by gas chromatography using flame ionization detection as described by Lilley (1983). Accompanying gases, hydrogen, and carbon dioxide were analyzed by using multiple-phase equilibrium and stripping techniques with GC detection (McAuliffe 1971). Nutrients in waters were analyzed as follows. Dissolved nutrients were filtered through acid-washed membrane filters; the concentrations were determined with an Autoanalyzer II (Strickland and Parsons 1972). Dissolved organic carbon samples were filtered through precombusted glass filters; the concentrations were determined according to Mensel and Vacarro (1964).

The Copper River Delta has numerous aquatic habitats where water chemistry is strongly influenced by gas chemical weathering and sources of CO_2. These waters can be identified by increases in total alkalinities (TA) and concentrations of divalent cations (Ca + Mg). Total divalent cations (Ca + Mg) concentrations were positively correlated ($r = 0.88$, $n = 36$) with TA (fig. 6), thereby indicating that carbonation is the major chemical mechanism causing the higher divalent cation concentrations. For all major habitats sampled, concentrations of Ca + Mg ranged from 30 to 582 micromoles and TA from 123 to 1216 milliequivalents per liter (table 3). Concentrations of cations greater than 400 nanomoles and TA greater than 600 milliequivalents per liter were found in Falls Slough, the marsh and beaver ponds in Alaganik and Pete Dahl Sloughs, Saddlebag Lake, the Copper River, a pond on Long Island in the Copper River, a beaver pond in the Martin River Slough, and a marsh pond on the Martin River flood plain. The importance of carbonation was confirmed by calculation of carbonate alkalinities (CA) for a random sample of waters in various habitats. For these habitats, CA averaged 84 percent of TA, with bicarbonate the dominant compound of CA. A high correlation coefficient (0.93, n=12) of Ca + Mg versus CA exists

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[2] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Table 3—Chemical characteristics (expressed as ranges) of waters in the major aquatic habitats of the Copper River Delta, July 1987

	Major habitats[a]			
Water chemistry	Rivers	Streams	Marsh ponds	Sloughs
Total alkalinity (meq/L)	270-1186	163-416	123-1216	319-904
pH		6.3-7.9	5.6-7.6	6.0-7.3
Temperature(°C)	8.5-11.2	4.6-18.7	17.0-24.0	10.0-24.0
Ca (μM)	15-451	79-221	18-517	58-353
Mg (μM)	24-100	11-44	22-65	16-179
Na (μM)	187-254	187-254	83-407	47-1173
Fe (μM)	0.5-44.0	0.5-5.6	0.5-252	0.5-63
DOC (mg/L)	2.1-5.3	1.2-10.5	3.5-19.0	3.5-16.8
Methane (nm)	19.8-31.2	1.6-1948	880-4825	1036-19663
Dissolved oxygen (mg/L)	8.2-10.0	8.6-9.6	3.8-92	2.1-10.6
Ammonium (μM)	0.7-14.6	1.9-21.8	6.1-32.0	0.0-55.0
Nitrite (μM)	0.06-0.30	0.01-0.18	0.00-0.09	0.00-0.33
Phosphate (μM)	0.70-1.24	0.07-.081	0.05-1.28	0.15-1.80
Silicate (μM)	57.9-109.7	13.0-121.6	0.17-68.3	30.2-148.6

[a] Concentrations are the range of values for groups of major habitats sampled during the survey.

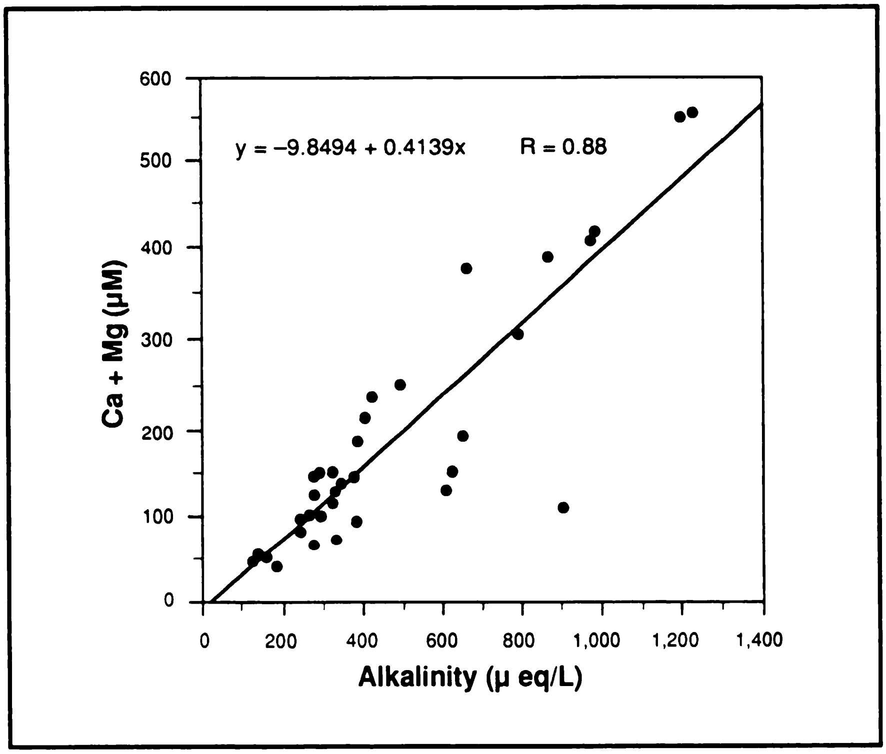

Figure 6—Relation of total concentration of calcium and magnesium (Ca + Mg) to total alkalinity in waters of aquatic habitats of the Copper River Delta.

for these samples. These characteristics indicate that the CO_2 system dominates the buffering capacity (Park 1969).

We surmise that decomposition of organic material from vegetation of marsh and pond environments is the primary source of CO_2. In addition, prolonged exposure of runoff waters from mountainous headwater streams and glaciers to atmospheric CO_2 at cold temperatures could increase CO_2 concentration in these waters. The increased solubility of the gas in cold waters suggests carbonate-based weathering reactions (Reynolds and Johnson 1972) proceed at higher rates in colder habitats (for example, glacier-fed lakes and streams) of the Copper River Delta.

In contrast to total divalent cations concentrations, the ratio of Na:(Na + Ca) can be used to show the relative importance of precipitation in determining the distribution of cationic constituents in waters (Gibbs 1970). The Na:(Na + Ca) values decrease exponentially as total alkalinity increases (fig. 7). The highest values for the ratio of Na:(Na + Ca)—greater than 0.60—were computed for the perched ponds in Falls Creek; Eyak River; Alaganik, Pete Dahl, and Martin River Sloughs; a beaver pond in the Martin River Slough; and in 39-Mile Creek. We postulate that the high residence time of rainwater in the pond habitats is important in determining the cationic compositions.

Besides carbonation reactions and precipitation, dissolved organic carbon (DOC) in waters of wetlands can have important influences on the ionic composition (Beck and others 1974; McKnight and others 1982, 1984; Oliver and others 1983). Dissolved organic carbon can be derived from microbial decomposition of organic matter as well as from plant leaching and excretion processes (Duff and others 1963, Wissmar 1986). The highest concentrations of DOC in the Copper River Delta habitats occur in marsh and beaver ponds and range from 5 to 19 milligrams per liter (fig. 8). These habitats include different types of marsh ponds: lily ponds (LP); equisetum-littoral ponds (EP); open ponds (OP); and large, deep ponds (DP). Beaver dams on sloughs (BS) and equisetum-littoral beaver dams in streams (BE) formed ponds having the highest DOC levels. All these habitats tend to deposit or store organic material, whereas the other habitats, such as streams and sloughs, usually transport material downstream.

Organic fractions of the DOC seemed to influence iron (Fe) concentrations in waters of the delta. As DOC and trace elements are flushed from saturated soils during periods of high rainfall and flooding, the fulvic acid fraction of the DOC can form stable complexes with Fe. These DOC-Fe complexes contribute greatly to the transport of Fe and other trace metals (for example, aluminum) (Beck and others 1974). Evidence of this phenomenon in the Copper River Delta is a positive relation between DOC and Fe (fig. 9). Iron can also occur in fine colloidal hydroxides and colloidial metal-organic complexes possibly associated with colloids composed of organics and glacial silt. Iron, whose concentration is commonly high compared to other trace metals, can play an important trophic role in microbially mediated oxidation-reduction reactions in many aquatic habitats (McKnight and others 1988).

The high DOC concentrations in marsh and beaver pond habitats of the delta, while reflecting influences of the accumulation of organic matter, correlate well with total dissolved inorganic nitrogen (DIN) concentrations (ammonium + nitrate + nitrate). These habitats had the highest DOC and DIN concentrations; streams and other habitats showed low concentrations. This was evident in the direct relation between DOC and DIN ($r = 0.75$; $n = 36$) (fig. 10). The relation points to the importance of internal recycling of organic matter and nutrients by different decomposition processes within pond habitat. The other

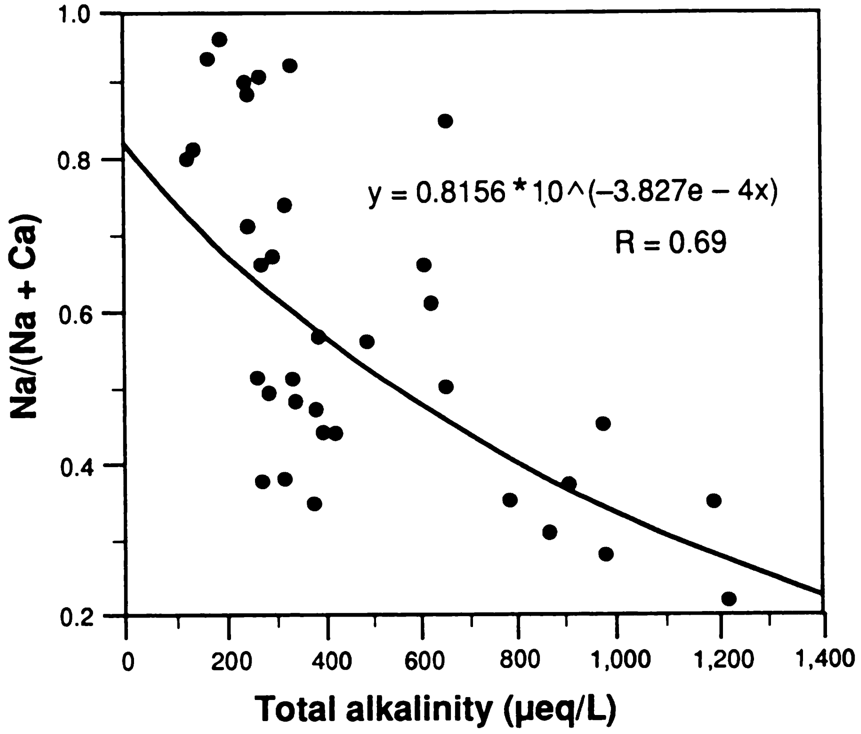

Figure 7—Relation of Na:(Na + Ca) ratio to total alkalinity in waters of aquatic habitats of the Copper River Delta.

habitats tend to be more dependent on external sources of nutrients.

The direct relation between methane (milligrams•meters^{-2}•day^{-1} from surface waters) and DOC concentrations provides additional evidence of the importance of internal processes in the recycling of organics (r = 0.64; n = 16) (fig. 11). This relation suggests higher methane fluxes in marsh ponds and habitats that accumulate large amounts of organic matter. Methane in the marsh and beaver ponds is produced by methanogenic bacteria in the organically rich, anoxic, benthic sediment deposits (Dahm and others 1987, Ford and Naiman 1988). Methane concentrations ranged from as low as 2 nanomoles in streams to 20 micromoles in ponds (table 3). Methane in pond habitats was supersaturated with respect to the atmosphere (2.0 nanomoles). For the nonpond habitats (for example, streams, rivers, and sloughs) of the delta, methane levels ranged from 22 to 1739 nanomoles and were similar to coastal rivers of Oregon (de Angelis and Lilley 1987).

Low concentrations of both nitrogen and phosphorus indicate that these nutrients limit primary production during the summer in most of the habitats of the Copper River Delta (table 3; fig. 12, A-D). Nitrogen:phosphorus (N:P) ratios for the different aquatic habitats of the Copper River Delta indicate different limiting situations. For comparative purposes, low N:P ratios (6:1 to 20:1) of saline waters indicate N-limitation; whereas higher ratios (>30:1), common for freshwater habitats, indicate P-limitation (Devol and Wissmar 1978, Nixon and Pilson 1983). The N:P ratios for aquatic habitats in the Copper River Delta show P limiting in most habitats (fig. 12 A-D) with both N and P possibly limiting in marsh ponds and

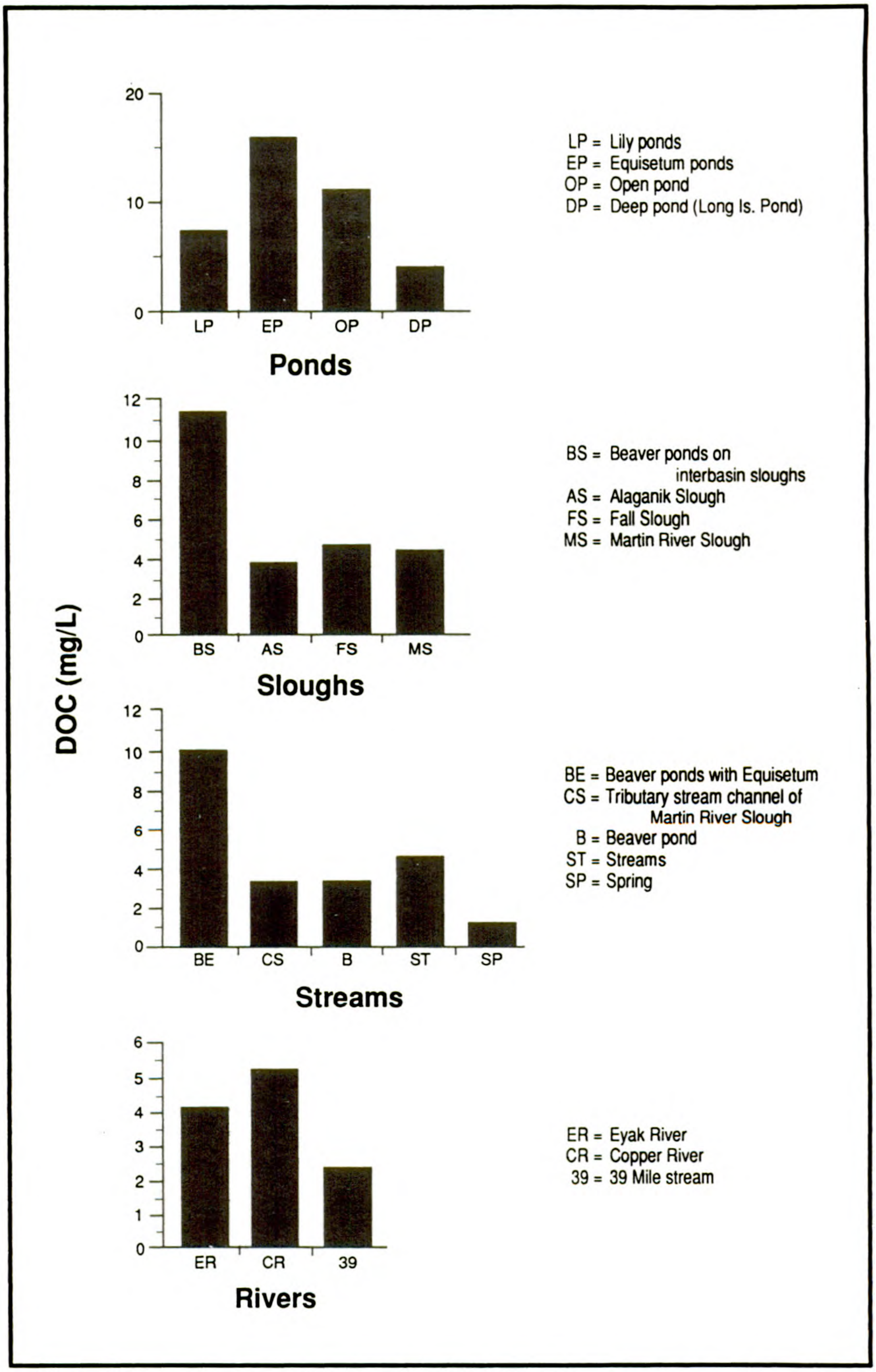

Figure 8—Dissolved organic carbon (DOC) in waters of aquatic habitats of the Copper River Delta.

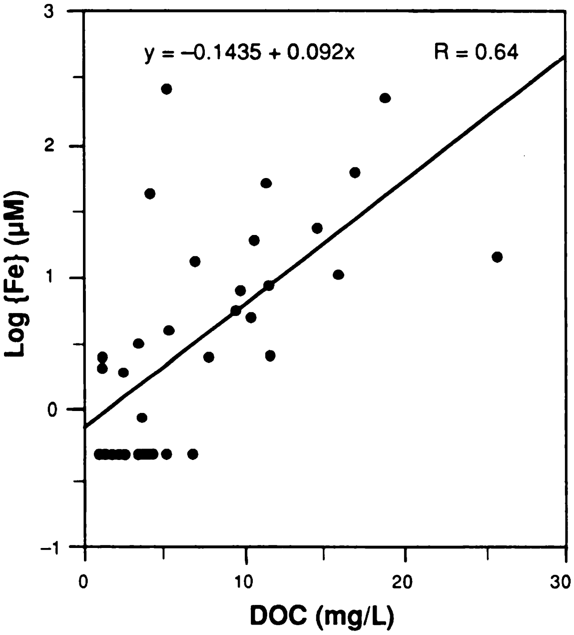

Figure 9—Relation of dissolved iron (FE) concentrations to dissolved organic carbon (DOC) in waters of aquatic habitats of the Copper River Delta.

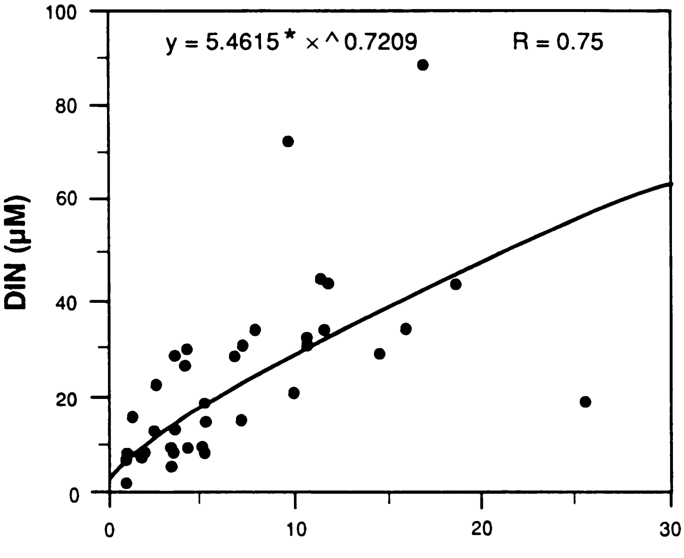

Figure 10—Relation of total dissolved inorganic nitrogen (DIN) to dissolved organic carbon (DOC) in waters of aquatic habitats of the Copper River Delta.

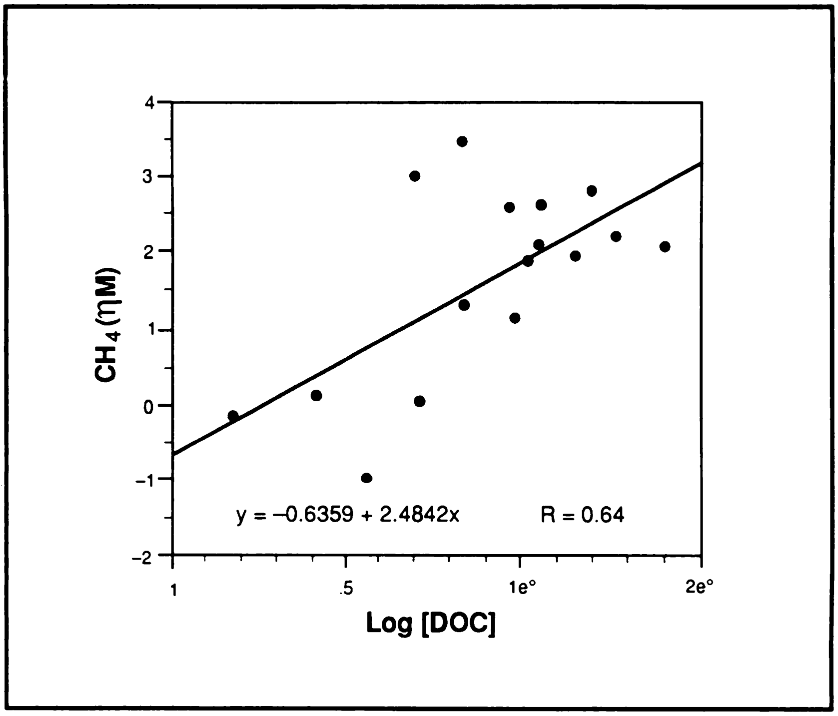

Figure 11—Relation of methane (CH_4) fluxes to dissolved organic carbon (DOC) in waters of aquatic habitats of the Copper River Delta.

sloughs. Concentrations of silicate, an important algal nutrient, were also low in many of the habitats.

Our observations indicated that to properly manage the Copper River Delta habitats, additional information will be needed about functional processes that maintain ecosystem and habitat productivity. The processes of major interest to future investigators include internal and external pathways of biogeochemical cycles; for example, in aquatic habitats like those in the Copper River Delta, internal cycling of DOC and nutrients can occur by translocation through plant roots and stems, soil diagenesis, bacterial processes, and animal activities (Kistritz and others 1983, Naiman and Melillo 1984, Naiman and others 1986, Wissmar 1986, Wissmar and others 1987). The importance of aquatic plants in translocating nutrients was suggested by the high phosphate and DIN concentrations in habitats (BE and EP) containing dense stands of *Equisetum* sp. (a rooted macrophyte) in beaver ponds (BE) of streams (fig. 12B) and *Equisetum* ponds (EP) in marshes (fig. 12C). Animal activities can also increase nutrient levels in both BE and BS habitats (fig. 12, B and D). Examples of important animal activities influencing nutrient cycling include foraging, excretion, and habitat structural modifications by benthic invertebrates and mammals (for example, beavers [*Castor canadensis*] and moose [*Alces alces*]).

Along with the recycling of nutrients (N and P) within aquatic habitats by microbes, plants and animals, N can be gained in habitats by plants that are capable of fixing atmospheric nitrogen (N-fixation). Nitrogen fixation in many delta habitats seems to be an important source of new nitrogen. High densities of N-fixing blue-green algae (for example, *Nostoc* sp.) were observed on the surface sediments of mud flats of the outer marsh. Other N-fixers on the delta include alder (*Alnus* sp.) and *Myrica gale* near stream and pond habitats. See chapter on "Plant Ecology."

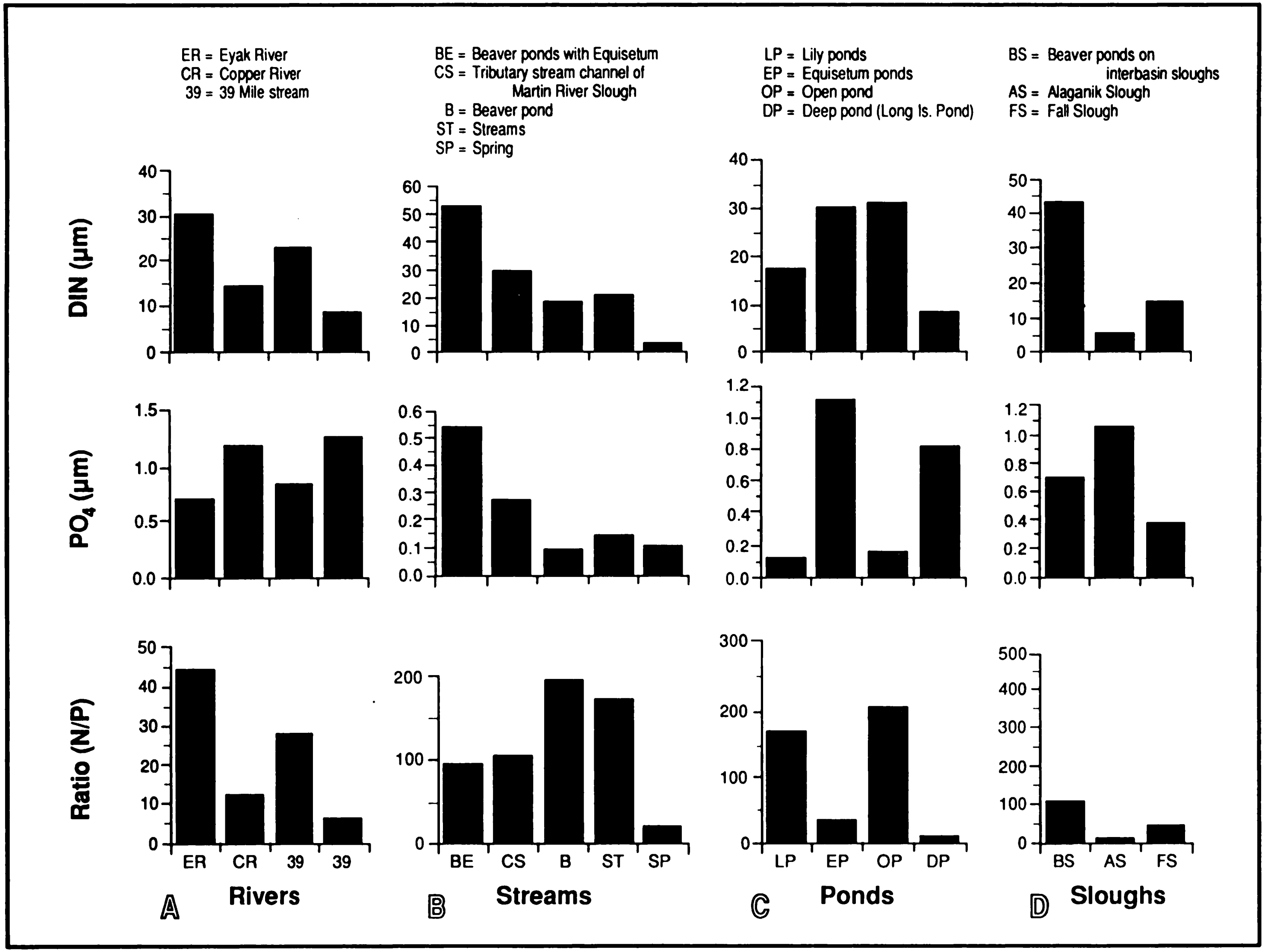

Figure 12—Total dissolved inorganic nitrogen (DIN), phosphate (PO_4) concentrations, and nitrogen-to-phosphate ratio (N/P) in waters of aquatic habitats of the Copper River Delta.

Phosphorus sources in the delta seem to differ depending on the season and the location of specific habitats; for example, important marine inputs of phosphate to many habitats in the outer marshes is likely during winter storms at high tidal periods. Inland habitats may gain phosphate from recently glaciated terrain. Phosphates can be released during weathering reactions associated with newly glaciated rock and deposits of nearby glaciers and river drainages.

Hydrologic regimes also can have important influences on both internal and external supplies of nutrients for different aquatic habitats. In many marsh and beaver ponds (BE and BS), a major factor in the recycling of nutrients is the long retention time for water masses (fig. 12). Longer retention times in the ponds influence a variety of plant-water and oxic-anoxic interfaces of sediments where numerous nutrient cycling reactions can occur (Wissmar and others 1987). Shorter water retention times occur in beaver ponds, but the dams are most likely important sites for nutrient recycling. Other major hydrologic influences include groundwater flows, floods, and storms. Hydrologic events such as floods and storms appear to have abrupt effects on nutrient cycling in many habitats.

We recommend that along with studies of biological and chemical functioning of habitats, that these features and changes in habitat characteristics be examined seasonally. Attention should be given to relating chemical, biological, and habitat structures to hydrologic and geomorphic influences. Important hydrologic features include precipitation on the delta and discharge regimes of the Copper River and the coastal rivers (for example, Eyak and Martin Rivers). This analysis would permit an assessment of how chemical characteristics of different regions and their habitats can be influenced by the timing and magnitude of floods of various rivers versus storage of direct rainfall and of large, sudden events like winter storms during high tides.

Determination of seasonal effects will set the stage for evaluating key factors influencing the productivity of aquatic habitats. Key factors include (a) timing and duration of water renewal by river inflows versus direct rainfall, (b) changes in water nutrient and sediment concentrations, (c) changes in habitat geomorphology (for example, deposition and erosion), (d) duration of ice cover, (e) length of the growing season, (f) anaerobic conditions in marsh benthic environments, (g) death of vegetation, and (h) influences of invertebrates (for example, insects) and herbivorous mammals (for example, beavers and moose). All these factors are linked to accumulation of organic matter and nutrient cycling in the habitats and habitat productivity. To properly manage the Copper River Delta habitats, future studies need to identify potential annual nutrient loading within a habitat compared to the capacity of the habitat to retain and cycle nutrients by plants and microbes. Habitats could be classified by their capacity to recycle nutrients (short- and long-term rates). The classification model would also identify habitats with "seasonally timed" exogenous loading rates (Wissmar 1986). The development of a habitat classification model for the Copper River Delta would facilitate the management of habitats based on their unique biological and chemical functions and hydrologic cycles.

Higher nutrient recycling rates and the productivity of various habitats may relate not only to greater water retention times but also to events in the river flood plains. The possibility exists that while the overall production of a habitat is sustained during most seasons by internal nutrient recycling, pulsed nutrient additions by floods during a specific season could alter the nutrient balance. Such alterations could cause two extreme situations. First, in poorly flushed habitats, increased nutrient concentrations could accelerate biochemical oxidation and reduction processes enhancing the loss of oxygen and nutrients (for example, denitrification or the loss of nitrogen to the atmosphere). Secondly, in moderately to frequently flushed habitats (beaver ponds and sloughs), higher nutrient loadings may stimulate primary and secondary production and increase the production of fish and wildlife.

Our water chemistry analyses showed that aquatic habitat types are diverse and complex and need to be managed based on unique biological and chemical functions of different habitat types. Ratios and concentrations of critical nutrients such as N and P differ widely among habitats. Definition of seasonal and hydrologic variation within habitats would facilitate understanding the many factors determining biological productivity in the aquatic habitats.

Algae Populations *Jerry Hilgert*[1]

Qualitative samples of algae were taken from selected sample sites throughout the Copper River Delta wetlands and included most sites listed in table 1. The Martin River Slough was not sampled. Samples were taken from the substrate by scraping rocks or removing samples of colonies in the water column or from the substrate. Identification was done with a compound microscope and further identification will be made with a scanning electron microscope.

In general, no phytoplankton and few periphyton were found in rivers and streams with large amounts of glacial silt; several genera of Chlorophyta (green algae) were found in the clear side channels (table 4). The colder streams (Otter Slough) next to the steep slopes of the Heney Mountains had very low species diversity. A green alga, *Tetraspora cylinorica*, was the dominant species; colonies up to 1 meter long and 20 millimeters in diameter were observed. Phytoplankton populations were most abundant in the interbasin slough channels. High diversities of diatoms also were observed in this habitat. Although not all have been identified, 30 to 50 taxa may be present. High concentrations of Chlorophyta also were observed (table 4).

Perched ponds (or slough ponds) are dominated by vascular plants and comprise the highest biomass compared to phytoplankton. The latter are diverse and primarily epiphytic taxa that, when jarred loose, may be important to zooplankton grazers.

Nostoc sp., an N-fixing blue-green alga, was found throughout perched ponds and open flats on the lower portions of the wetlands. It may be an important source of N in these areas. Colonies become sparser as the sedges become more abundant. There may be four or five species, but they have not been identified.

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Table 4—Phytoplankton and algae identified from samples taken on the Copper River Delta wetlands, July 20-27, 1987

Habitat type	Location	Phytoplankton species identified
River and streams:		
Glacial	Ibek Creek	Chlorophyta:
		Zygema
		Ulothrix
Upland clearwater	Falls Creek	Chlorophyta:
		Spirogyra
		Microsora
	Others	Few diatoms
	Tributaries	Pennate diatoms:
		Cymbella
		Fragilaria
		Hannaea arcus
		Diatoma hiemale
		Diatoma vugaris
Sloughs:		
Clearwater	Otter Slough	Diatoms (sparse):
		Chlorophyta
		Tetraspora cylindrica
Glacial (partial)	Alaganik Slough	Chlorophyta:
		Oedogonium
		Microspira
		Diatoms:
		Tabellarice fenestrata
		T. flocculosa
		+30-40 other species not identified.

Zooplankton and Macroinvertebrate Populations

J.R. Sedell, M.D. Bryant, C.A. Hawkins, and N.W. Wissman[1]

Sixteen benthic samples were taken from representative aquatic habitats throughout the Copper River Delta to obtain a qualitative sample of the taxa in each habitat. Samples were washed in a 500-micron sieve and floated in white enamel pans. More than 99 percent of organisms were recovered by this method. Most macroinvertebrates were identified to genus.

Crustacea and Chironomidae were the most abundant taxa in the samples (fig. 13). Crustaceans were most abundant in the new marsh and old marsh sloughs and in the wetland ponds (fig. 13). In the ponds, Crustacea was comprised almost solely of Cladocera; cladocerans were absent in all other habitats. In the new marsh, *Neomysis mercedis* (an euryhaline mysid) was the dominant organism (fig. 14). It was followed in abundance by the amphipod *Eorophium spinicorne*, the most abundant crustacean in the old marsh sloughs (fig. 14).

Chironomidae was the dominant taxon in the samples from the ponds, the Mountain Slough drainage, and Ibek Creek. Chironomids were also abundant in the old marsh sloughs. Within this group a few genera were dominant: *Orthocladius*, in Ibek Creek and from the Mountain Slough area; and *Micropsectra*, from the Old Marsh Slough and Mountain Slough drainage. Fewer genera were found in the Mountain Slough drainage and from upper Ibek Creek (fig. 15); both habitat types were colder than the others that were sampled.

The wetland ponds—including beaver ponds and a perched pond—had more invertebrate taxa than did other habitat types. Representatives of Odonata and Hemiptera were found only in the perched ponds. Ibek Creek had the fewest taxa but was the only habitat type, other than the ponds, where Ephemeroptera were found (fig. 13, C and E). The invertebrate Crustacea populations, particularly *Neomysis*, in the new marsh and old marsh reflect the intertidal influence.

The results from this limited sample suggest that ponds are more productive than many of the colder slough-habitat types. It seems, furthermore, that crustaceans may be a more important food source for juvenile salmonids in the intertidal sloughs, whereas chironomids are probably more important in the old marsh and pond habitat types. Additional work is required to determine the role of the invertebrate community in the trophic structure of those habitat types.

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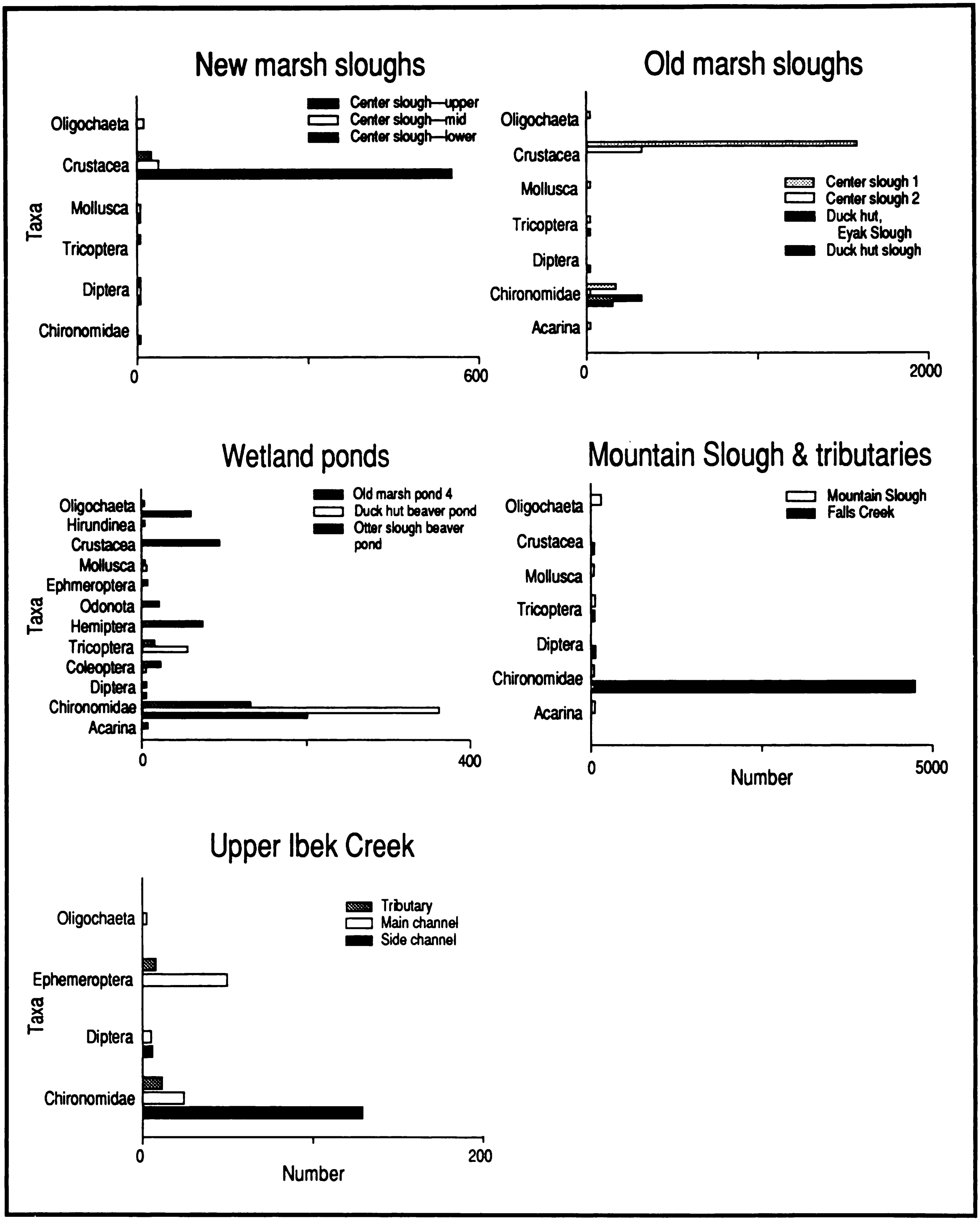

Figure 13—Macroinvertebrate taxa collected from aquatic habitats of the Copper River Delta.

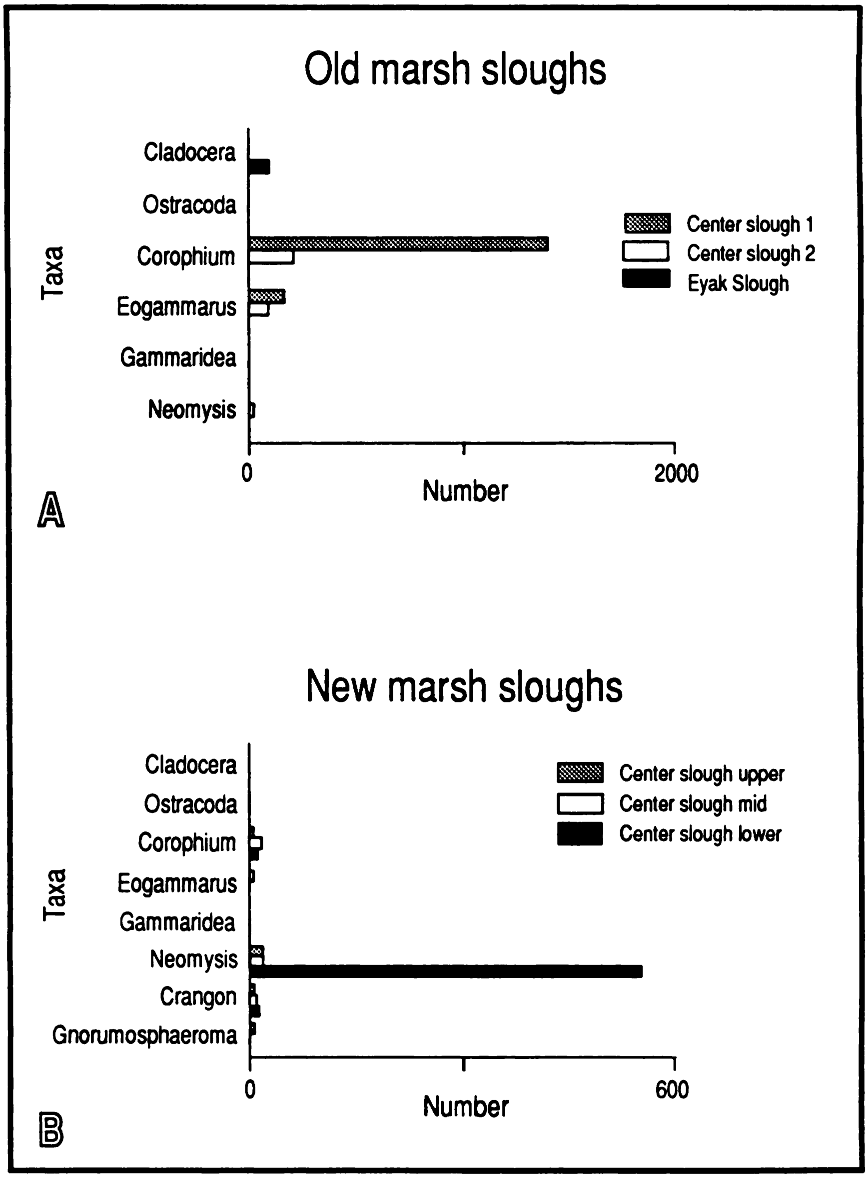

Figure 14—Crustacea collected from the sloughs of the Copper River Delta.

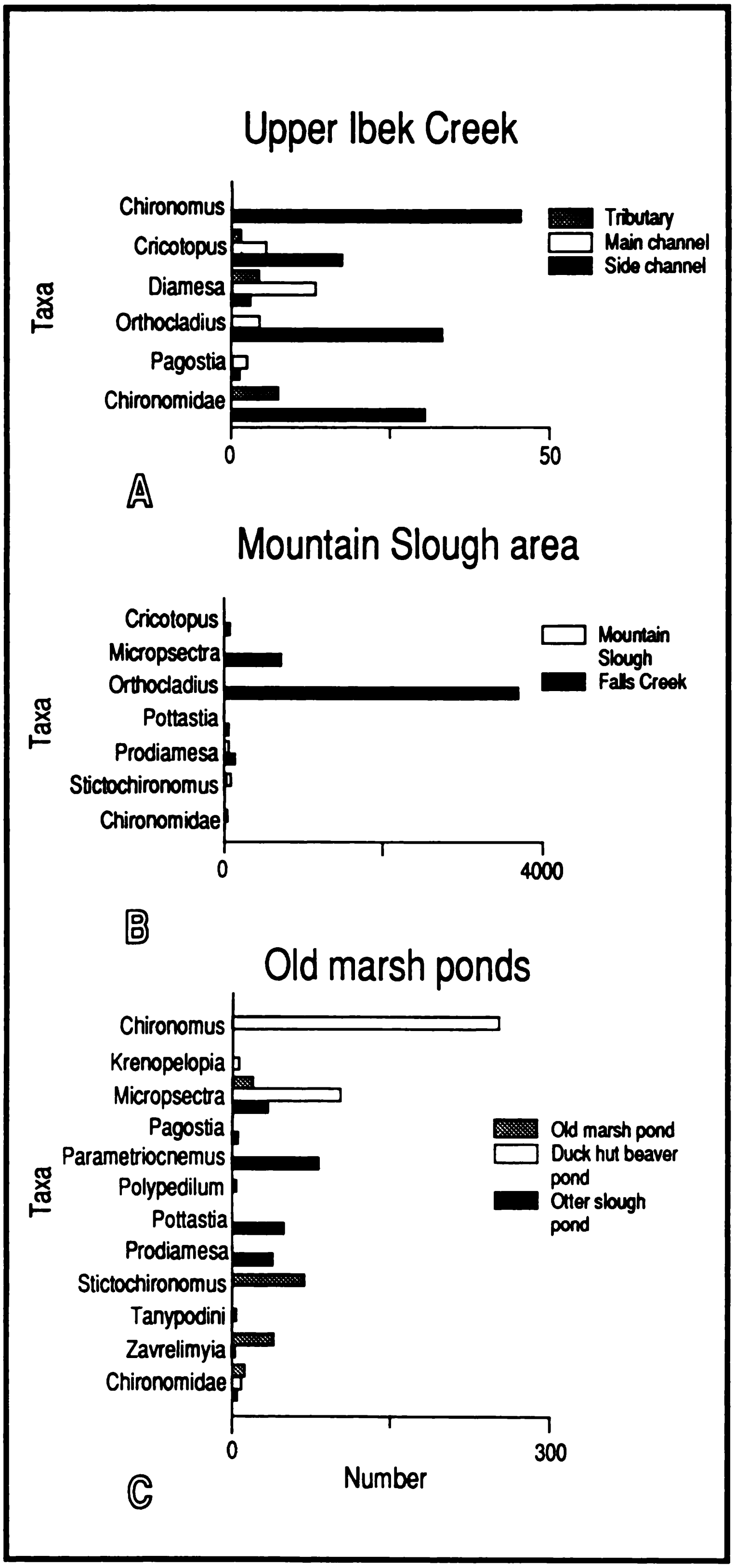

Figure 15—Chironomidae collected from the aquatic habitat of the Copper River Delta.

Anadromous Fish Habitat: Distribution of Juvenile Salmonids

M.D. Bryant, F. Everest, G. Reeves, J.R. Sedell, and R.C. Wissmar[1]

Salmonid populations were sampled in all major habitat types; fyke nets, minnow traps baited with salmon eggs, and snorkel counts were used. Habitat types included forest streams, clearwater tributaries, interbasin slough channels, distributary slough channels, and beaver ponds west of the Copper River Delta sloughs (table 1); beaver ponds and tributaries in the Martin River Slough drainage also were sampled (fig. 1). All fish captured in minnow traps and fyke nets were identified and measured. A sample of the catch was weighed, and stomach contents were taken by flushing (Meehan and Miller 1978). A few (less than 50) otoliths were taken to determine fish age and growth. Average lengths, species distribution, and habitat use are reported here.

Coho salmon were captured in all habitats sampled with minnow traps and were the dominant species. Coho salmon comprised more than 90 percent of the fish sampled in all ponds (table 5). Dolly Varden also were common throughout most habitats but were less common in the interbasin slough channels and beaver ponds than in the upland tributaries and ponds (table 5). Cutthroat trout generally were not captured in the sloughs but were found throughout the upland tributaries and ponds (table 5). Sockeye salmon were not captured in minnow traps but in seines and fyke nets set in the intertidal sloughs. Sockeye salmon did not seem to be vulnerable to minnow traps. Most sockeye salmon juveniles were captured in the Martin River Slough in an overnight fyke net set (table 6).

Most coho salmon captured in the interbasin slough channels and beaver ponds appeared to be age 1+ or older, based on the length and frequency distribution of the total catch in minnow traps. The forest streams showed 22 percent of the catch to be coho salmon that were less than 51 millimeters in fork length (FL); they were considered young-of-the-year fry (table 7). Elsewhere they were less than 11 percent of the total catch. Although minnow traps are more efficient for capturing larger juvenile coho salmon (generally greater than 55 millimeters), the higher proportion of fry in the forest streams seems to reflect the location of spawning areas. Riffles and runs with gravel substrate were common throughout these streams and likely provide high-quality spawning habitat. Coho salmon populations in the sloughs and ponds seem to be the result of downstream migration from these streams.

Few salmonids were counted during snorkel surveys in the clearwater sloughs of the Martin River Slough. The substrate was composed mostly of hard blue-gray sediment. Juvenile salmonids, primarily coho salmon, were observed in the main channel of the Martin River Slough when the substrate was pea-size gravel but were difficult to count because of the many spawning sockeye salmon. No fish were observed in the clear streams surveyed along the base of the Heney Range. All these streams are fed directly from the side slopes of the mountains, and water temperatures were less than 6 °C throughout the streams when they were sampled. Upper Ibek Creek is a clear, cold, high-velocity stream draining a narrow valley in the upper watershed. Few salmonids were observed in the small section

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Table 5—Number and percentage of salmonids captured in locations sampled with minnow traps, July 1987

Location	Coho salmon		Cutthroat trout		Dolly Varden char	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Duck Hut Pond	56	96.6	1	1.7	1	1.7
Daisy Slough	55	83.3	0	0	11	16.7
3-Dam Slough	227	100.0	0	0	0	0
Circle Slough	276	100.0	0	0	0	0
Meadowbrook	318	59.2	66	12.3	153	28.5
18-Mile Pond	904	98.6	6	0.7	7	0.8
18-Mile Downstream	363	93.3	6	1.5	20	5.1
Wimp Creek	409	66.5	17	2.8	189	30.7

Table 6—Salmonids captured in a Martin River Slough tributary in 2 12-hour fyke net sets

Species	Number caught	Mean fork length	Standard deviation
		Millimeters	
Set 1:[a]			
Sockeye salmon	24	65.2	8.2
Coho salmon	43	70.2	16.3
Dolly Varden char	7	117.6	11.8
Set 2:[b]			
Sockeye salmon	83	65.5	6.6
Coho salmon	71	76.4	14.7
Dolly Varden char	7	124.9	28.1

[a] 1600-2100 hours, 27 July.
[b] 2200 hours, 27 July to 1300 hours 28 July.

Table 7—Percentage of coho salmon fry (fish less than 51 millimeters fork length) and modes of the length frequencies of fry and parr in major habitat types, Copper River Delta wetlands

Habitat	Less than 51 mm (fork length)	Mode	
		<51 mm	≥51 mm
	Percent		
Clear tributaries	22	42	77
Upland ponds	2	47	83
Sloughs	11	47	82
Slough ponds	10	47	82

surveyed near the base of Scott Glacier. Surveys of Scott River were made above the road in the braided outwash channel in clear water. Most juvenile coho salmon were observed along the stream margins. Several hundred juvenile coho salmon were observed in Meadowbrook Creek, which drains a forested area above the highway (table 8).

Fyke nets were set at several locations in tidal areas of several distributary slough channels. Overnight sets at Pete Dahl, Johnson, and Tiedeman Sloughs caught few fish. At Pete Dahl Slough, two coho salmon fry and several sculpins (*Leptocottus armatus*), ranging from 29 to 56 millimeters in length, were captured. About 23 salmonids (species not identified), about 100 sticklebacks (*Gasterosteus aculeatus*), 62 sculpins, and 5 whitefish (*Prosopium* sp.) about 220 millimeters in length were captured at Tiedeman Slough. Less than 20 juvenile sockeye salmon and less than 10 sculpins were captured in the fyke net set at Government Slough. No significant movements of salmonids appeared in these sets; however, juvenile sockeye salmon seemed to use the sloughs. Sculpins are potential predators on juvenile salmonids.

Two 12-hour fyke net sets on a tributary of the Martin River Slough captured 107 juvenile sockeye salmon having a mean fork length of 65.5 millimeters and 114 juvenile coho salmon having mean fork length of 70.2 millimeters (table 6). Fourteen Dolly Varden were captured, and most were greater than 100 millimeters. Although movement patterns were not clear, juvenile salmonids seemed to use the intertidal sloughs, particularly during high tides. Salmonids in these sloughs may move in and out on the tidal cycle. Several large sculpins were captured in the fyke net and had eaten several salmonids and smaller fish.

It is apparent from the results of this limited sample that juvenile coho salmon and sockeye salmon are distributed throughout most aquatic habitat types in the wetlands. Some exceptions were the perched ponds on the wetlands and the major waterways with heavy amounts of glacial silt. Although they were not extensively sampled, few salmonids were captured or observed in either habitat type. The edges and off-channel habitats of the main-stem rivers may be used by juvenile sockeye and coho salmon.

Distribution of the size classes of coho salmon may be related to the proximity of spawning habitat to rearing habitat. Recruitment of juvenile salmonids to most habitats in the lower wetlands seems to depend on downstream migration. Juvenile sockeye salmon were not observed in the few clearwater tributaries surveyed but seemed to be common in the intertidal sloughs. Sockeye salmon fry probably move into sloughs from spawning areas identified by Roberson and others (1974) in Eyak Lake, Ibek Creek, and the streams and beaver ponds near the 25-mile point on the Copper River highway, as well as off-channel habitat near the main channels of the Copper River, Martin River, and Martin River Slough.

There are no lakes in the Martin River Slough system, and only a few small beaver ponds are found in the 25-mile system; therefore, the intertidal sloughs may be important rearing areas for juvenile sockeye salmon produced in these basins. Samples from fyke nets indicated that juvenile sockeye salmon may move into and out of sloughs with the tide, but virtually nothing is known about their distribution and their use of the fresh waters of the Martin River Slough system.

Table 8—Snorkel counts of juvenile coho salmon of the Copper River Delta wetlands

Area	Habitat	Total number		Number per square meter	
		Fry	*Parr*	*Fry*	*Parr*
Meadowbrook:	Clearwater tributary:				
Lower	Open meadow	109	121	0.25	0.28
Upper	Forested	264	40	.46	.07
Cannery Slough:					
All 4 streams	Wall base, clear tributaries	0	0	0	0
Ibek Creek[a]	Clear water, tributary	0	0	0	0
Scott River	Glacial outwash stream	100	0	.001	
Martin River Slough[b]	Clearwater tributaries	0	0	0	

[a] Few Dolly Varden fry.

[b] Abundant (no counts due to sockeye spawning).

Plant Ecology

P. Alaback, R. Naiman, and J. Pastor[1]

Three basic plant ecological studies were begun in 1987: (1) a general survey of plant species composition, abundance, and diversity in relation to substrate age, soil fertility, and elevation; (2) comparison of soil fertility and plant community structure in relation to animal browsing; and (3) a general description of plant successional processes in relation to beavers and other herbivores.

Plant Communities

Methods—Fifteen sites were sampled by using the techniques of Daubenmire (1959). In each site, thirty 0.1-square-meter plots were established. Percentage of cover of all species was recorded, and a soil sample was taken at each plot. Because the vegetation was stratified into bryophyte, herb, and shrub layers, total ground cover for an individual plot often exceeded 100 percent. Mean cover was estimated for each species in each site, and species frequency was calculated as the number of occurrences divided by the number of plots. When individual species could not be reliably identified in the field, samples were collected for later identification. Not all sample specimens were classified (especially the bryophytes). The data from two main sample areas are presented here: Eyak Slough, a wetland with minimal influence from saltwater due to the longshore current that carries freshwater from the Copper River northwesterly along the face of the marsh (Thilenius 1990). In contrast, the Martin River area, east of the Copper River, has intertidal characteristics with tidal flooding and coarse sediment particle deposition.

Preliminary results—A predictable pattern of increases in vegetative cover was noted with increasing substrate age and elevation at both sites. The youngest terrain in the Eyak Slough was colonized by four species of plants, including one bryophyte (*Brachythecium* sp.) (table 9). A significant portion of the ground was not vegetated. The site was a nearly pure mosaic of bare ground and clumps of *Carex lyngbyaei.* A second plot, transitional between the foreshore levee and the outer coast, had over three times the number of species and much greater ground coverage. The N-fixer *Myrica gale* was present but not common. The site was dominated by *C. lyngbyaei* and the feather moss *Rhytidiadelphus*. The foreshore levee, by contrast, had four additional species. It too was dominated by *C. lyngbyaei* and grass species and had nearly continuous ground coverage. The legume *Lathyrus* was common and could be a significant N-contributor to soil. An organic horizon in the soil was developing rapidly in this ecosystem.

Species diversity was generally greater at Martin River than at Eyak River (table 10). This could be the result of greater diversity of hydrological conditions; better soils, drainage, and fertility; or a less dramatic response to the 1964 earthquake. The outer coast at Martin River had about twice the number of species found on the outer coast at the Eyak River. Carpet-forming mosses were particularly abundant, and *C. lyngbyaei* was less dominant at the Martin River sites than at the Eyak River sites (40 percent vs. 93 percent ground cover). The transitional transects and the upper meadow were similar in species richness to the foreshore levee at the Eyak River. A notable feature of all transitional ecosystems was the high dominance by *Sphagnum* spp. Water moving directly below the *Sphagnum*

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Table 9—Vegetation species composition at the Eyak Slough study area, Copper River Delta, based on averages from 30 plots at each site, July 22, 1987

	New marsh		Transition		Levee	
Species	Cover	Freq.	Cover	Freq.	Cover	Freq.
Shrubs:						
Myrica gale	—	—	3.3	0.7	—	—
Salix barclayi	—	—	2.7	.2	—	—
Graminoids:						
Calamagrostis inexpansa	—	—	.2	.2	13.9	15.0
Carex lyngbyei	93.3	1.0	75.3	1.7	71.0	27.0
Deschampsia beringiana	—	—	.6	.5	4.2	15.0
Eriophorum russeolum	—	—	—	—	8.4	4.0
Juncus arcticus	—	—	7.6	.5	—	—
Poa eminens	—	—	3.7	.8	1.2	12.0
Poa palustris	—	—	—	—	.5	3.0
Puccinella nutkana	—	—	—	—	1.7	10.0
Herbs:						
Chrysanthemum arcticum	—	—	.6	.3	—	—
Cicuta mackenziena	—	—	—	—	3.0	13.0
Epilobium glandulosum	—	—	—	—	.5	5.0
Galium oreganum	—	—	—	—	.4	9.0
Iris setosa	—	—	—	—	.1	1.0
Lathyrus palustris	—	—	—	—	3.8	9.0
Lysimachia thrysiflora	—	—	—	—	1.4	18.0
Parnassia parvifolia	—	—	2.4	.7	—	—
Potentilla egedii	8.3	1.0	17.0	1.7	—	—
Ranunculus hyperboreus	1.9	1.0	2.2	.8	—	—
Ranunculus pacificus	—	—	—	—	.1	2.0
Bryophytes:						
Brachythecium asperimum	—	—	1.3	.5	—	—
Moss spp.	1.0	.7	—	—	—	—
Peltigera canina	—	—	—	—	—	2.0
Rhizomnium glabrescens	—	—	—	—	—	6.0
Rhytidiadelphus loreus	—	—	6.4	1.5	—	22.0
Total species	4		13		17	

and little soil development were observed on several transects. The greatest species richness was encountered in a lupine-dominated meadow and a levee of the Martin River. These ecosystems were dominated by conifers, sedges and grasses, and *Lathyrus*, which could be an important N-fixer.

From this preliminary sampling of the ecosystems in the Copper River area, we hypothesize that there is a wide range of plant successional responses to the complex interactions

Table 10—Vegetation species composition at the Martin River Slough study area, Copper River Delta

	Martin River Slough habitats											
	New marsh		Transition		Meadow		Lupine		Levee		Ibek Pond	
Species	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Trees:												
Picea sitchensis	—	—	—	—	0.1	0.06	4.7	0.1	55.6	0.6	0.1	0.03
Tsuga heterophylla	—	—	—	—	—	—	—	—	13.9	.2	—	—
Shrubs:												
Alnus sitchensis	—	—	—	—	—	—	—	—	—	—	.8	—
Myrica gale	—	—	4.5	0.2	—	—	—	—	—	—	—	—
Salix barclayi	—	—	—	—	—	—	.3	.03	2.8	.03	5.6	.2
Salix commutata	—	—	—	—	—	—	—	—	47.3	.03	—	—
Graminoids:												
Carex anthoxantha	—	—	.01	.03	—	—	—	—	—	—	—	—
Carex aquatilis	—	—	—	—	—	—	—	—	—	—	.3	.1
Calamagrostis inexpansa	—	—	38.5	1.0	5.7	.3	34.1	.9	—	—	39.6	1.0
Carex lyngbyei	40.3	1.0	3.2	.1	85.8	1.0	68.3	.9	1.7	.5	7.8	.2
Carex pluriflora	—	—	—	—	—	—	—	—	13.9	.3	—	—
Deschampsia beringiana	1.0	0.3	1.2	.2	.4	.1	1.6	.2	2.8	.1	.2	.1
Juncus arcticus	—	—	—	—	—	—	—	—	—	—	.1	.03
Jucus spp.	—	—	.3	.07	—	—	—	—	—	—	—	—
Poa eminens	—	—	—	—	2.2	.3	2.9	.4	.3	.1	.7	.1
Puccinella nutkana	—	—	.01	.03	—	—	—	—	—	—	—	—
Herbs:												
Chrysanthemum arcticum	—	—	—	—	—	—	—	—	.3	.3	—	—
Cicuta menziesii	—	—	—	—	1.7	.1	.2	.1	—	—	—	—
Epilobium angustifolium	—	—	—	—	—	—	—	—	2.8	.2	—	—
Epilobium arcticum	—	—	.3	.1	1.3	.7	—	—	—	—	—	—
Epilobium gladulosum	—	—	—	—	.2	.06	.1	.1	—	—	—	—
Epilobium spp.	—	—	.1	.03	1.3	.3	—	—	—	—	—	—
Equisetum spp.	—	—	—	—	—	—	—	—	5.6	.03	—	—
Equisetum arvense	—	—	—	—	.6	.1	—	—	2.8	.2	8.5	.6
Galium oreganum	—	—	—	—	—	—	—	—	—	—	—	—
Galium trifidum	—	—	—	—	.1	.1	.2	.1	—	—	—	—
Iris setosa	—	—	—	—	—	—	—	—	—	—	—	—
Lathyrus palustris	—	—	—	—	—	—	—	—	.8	.1	—	—
Ligusticum scoticum	—	—	—	—	—	—	—	—	8.3	.3	—	—
Lupinus nootkatensis	—	—	73.5	1.0	—	—	41.2	.9	1.1	.1	55.7	1.0
Lysimachia thrysiflora	—	—	—	—	—	—	—	—	—	—	—	—
Parnassia pavifolia	—	—	.1	.1	—	—	—	—	—	—	—	—
Plantago maritima	3.1	.4	—	—	—	—	—	—	—	—	—	—
Potentilla egedii	3.3	.9	2.8	.5	.3	.1	—	—	—	—	—	—
Potentilla palustris	—	—	—	—	—	—	1.0	.1	—	—	—	—
Potomogeton spp.	—	—	—	—	—	—	.4	.1	—	—	—	—
Prenanthes alata	—	—	—	—	—	—	—	—	.3	.03	—	—
Ranunculus hyperboreus	.4	.2	—	—	—	—	—	—	—	—	—	—
Rhinanthes minor	—	—	.2	.1	—	—	—	—	—	—	—	—
Stellaria sitchana	—	—	—	—	—	—	.7	.3	—	—	—	—
Trientalis europea	—	—	—	—	1.5	.1	—	—	—	—	—	—
Triglochin maritima	—	—	.01	.03	—	—	—	—	—	—	—	—
Viola langsdorfii	—	—	—	—	—	—	.1	.2	—	—	—	—
Bryophytes:												
Brachythecium asperimum	.6	.1	—	—	—	—	—	—	1.4	.1	—	—
Hylocomium splendens	—	—	—	—	—	—	—	—	—	—	2.8	.2
Isothecium spiculiferum	—	—	—	—	—	—	—	—	—	—	.2	.03
Jungermanniales spp.	—	—	—	—	—	—	—	—	—	—	.8	.1
Moss spp.	21.3	.5	30.5	.5	—	—	—	—	27.8	.2	1.7	.1
Peltigera canina	—	—	—	—	—	—	—	—	—	—	3.5	.5
Plagiothecium undulatum	—	—	—	—	—	—	—	—	—	—	.01	.03
Polytrichum commune	—	—	.5	.1	—	—	—	—	2.0	.03	—	—
Pogonatum juniperinum	—	—	—	—	—	—	—	—	—	—	1.6	.3
Ptillum crista-castrenis	—	—	—	—	—	—	—	—	—	—	.5	.03
Rhizomnium glabrescens	—	—	—	—	—	—	.4	.1	—	—	1.3	.1
Rhytidiadelphus loreus	—	—	—	—	—	—	.8	.1	5.6	.1	5.0	.8
Sphagnum girgensonii	.5	.2	—	—	—	—	—	—	—	—	—	—
Sphagnum squarossum	—	—	91.0	1.0	52.7	.7	2.2	.5	—	—	—	—
Total number of species:	9		14		13		19		20		20	

of tectonic activity, periodic flooding and rapid hydrological changes, and soil development in the region. Although the area is relatively species impoverished, careful measurement of soils and vegetative characteristics may shed some light on some of the physical and biotic successional processes and their interactions.

The potential for many ecosystem types in the delta exists, and some additions to the communities described by Crow (1968), Thilenius (1990), and others may be needed to fully describe the range of ecosystems sampled in our brief survey. The inclusion of bryophytes in these surveys would be particularly useful, because we saw a large and consistent contrast in this group among study sites.

Plant and Herbivore Interactions

During July 1987, soils and vegetation were sampled in the Copper River Delta to determine the possible effects of large herbivores, such as moose and beaver, on ecosystem properties. Additional soil samples were obtained from portions of delta exposed after the 1964 earthquake and higher portions of the delta that had been previously exposed. Analyses are proceeding on these samples and are nearly complete for samples obtained from inside and outside two moose exclosures. The latter analyses are reported here.

Moose browse selectively on hardwoods such as aspen (*Populus tremuloides*) and willows (*Salix* sp.) and avoid conifers such as spruce (*Picea* sp.) because spruce and other conifers are not as digestible and do not have the nutritious tissues that the hardwoods do. Many of the same properties affecting digestion in rumen of moose also determine decomposition rates in the soil, because both digestion and decomposition rates in the soil are microbially mediated. We therefore hypothesize that selective browsing by moose causes an increase in the abundance of unbrowsed spruce, whose slowly decomposing litter should depress soil N-availability and soil N-pools (Naiman and Pastor 1989). We also are assuming that moose browsing does not increase the abundance of N-fixing species such as sweetgale and lupine. Insofar as N is the limiting nutrient in most northern ecosystems, the depression of N-availability also may depress productivity and future browse for herbivores. We have been testing this hypothesis by using four 40-year-old moose exclosures in Isle Royal National Park, Michigan. These four exclosures are in habitats characteristic of the eastern portion of the range of moose, which is distinguished by upland boreal forest or small wetlands. The two moose exclosures in the Copper River Delta give us an opportunity to test this hypothesis in the contrasting moose habitat characteristic of much of southcentral Alaska, which is large, glacially fed river valleys with poorly developed soils.

The two exclosures were different ages and in different vegetation communities. The new exclosures were 8 years old at the time of sampling and in a community dominated purely by willow. The older exclosure was about 20 years old at the time of sampling and on an older substrate.

The vegetation was inventoried inside and outside both exclosures with 15 point-quarter sampling plots. Species, diameter, stem length, browse intensity, and probable herbivore use (moose or hare) were noted. These data have not been fully analyzed, but a few observations can be made: The vegetation inside and outside the new exclosure is almost purely willow with an understory of sweetgale, and heights generally are 1 meter or less.

Outside the old exclosure, browsing is also moderate to high on the willows, but there was considerable evidence of browsing by hare besides that by moose. Spruce is the only species growing above browse height outside the exclosure and was more abundant outside the exclosure than inside. Inside, heights of willows are 2 meters or greater;

outside heights rarely were greater than I meter and never greater than 1.5 meters. The heavy browsing seems to be responsible for altering community composition toward a greater abundance of spruce. It is assumed that by diminishing the stature of the willow, moose browsing is creating the competitive status of spruce.

Ten soil samples were obtained from the upper 10 centimeters of the profile inside and outside each enclosure. This depth included a thin (< 5 centimeters) humus horizon. Samples were randomly composited by two for a total of five samples per treatment on each site for subsequent analyses of total C, total N, and potential N-availability. Total C and N were measured by using a LECO CHN Analyzer. Potential N-availability was assessed by incubating the soils at 30 °C and periodically leaching all inorganic (plant-available) nitrate and ammonium with 0.01N $CaCl_2$, followed by additions of Hoagland's solution minus N. The incubations will continue for 30 weeks; we report here the cumulative N mineralized at the extraction after 22 weeks. All results were analyzed by analysis of variance (ANOVA) for main effects of site and treatment (exclosure or control in a two-way ANOVA), the effect of treatment within each site, and the effect of site difference with each treatment.

There were no significant effects of site or treatment on total soil C, which averaged 3.5 percent across all samples. At each site, there were no significant differences between enclosure and controls; however, there were significant site effects on total soil N and mineralization rate, depending on treatment. Total soil N was significantly greater inside the old exclosure compared with the new exclosure, even though there were no significant differences between the sites outside the exclosures (fig. 16). Protection from moose browsing apparently causes an increase in soil N with time. In contrast, N-availability was significantly lower outside the old exclosure compared with outside the new exclosure, but there were no significant differences between the soils inside the two exclosures. In this case, moose browsing causes differences between sites, but protection from browsing causes a convergence in soil N-availability with time.

The differences between the sites in N-availability in browsed plots might be attributed to the greater proportion of spruce at the old site compared with the new site, which depressed N-availability. The greater portion of spruce is due to a nearby seed source and the absence of browsing by moose on this species. Protection from moose at both sites allows willows to recover from browsing, so that they then dominate plant litter inputs and thereby cause N-availability inside both exclosures to converge. Thus, while moose browsing may not affect mean soil N-availability, it does seem to cause an increase in site-to-site variability.

The differences between the sites in total soil N are more problematic. The increased growth of willow, when protected from browsing, possibly results in greater litter input to soils, which in turn, over time, increases total soil N-pools. Moose browsing on willows in the Copper River Delta may accelerate the rate of natural succession to spruce by changing the fertility of the soil and community structure.

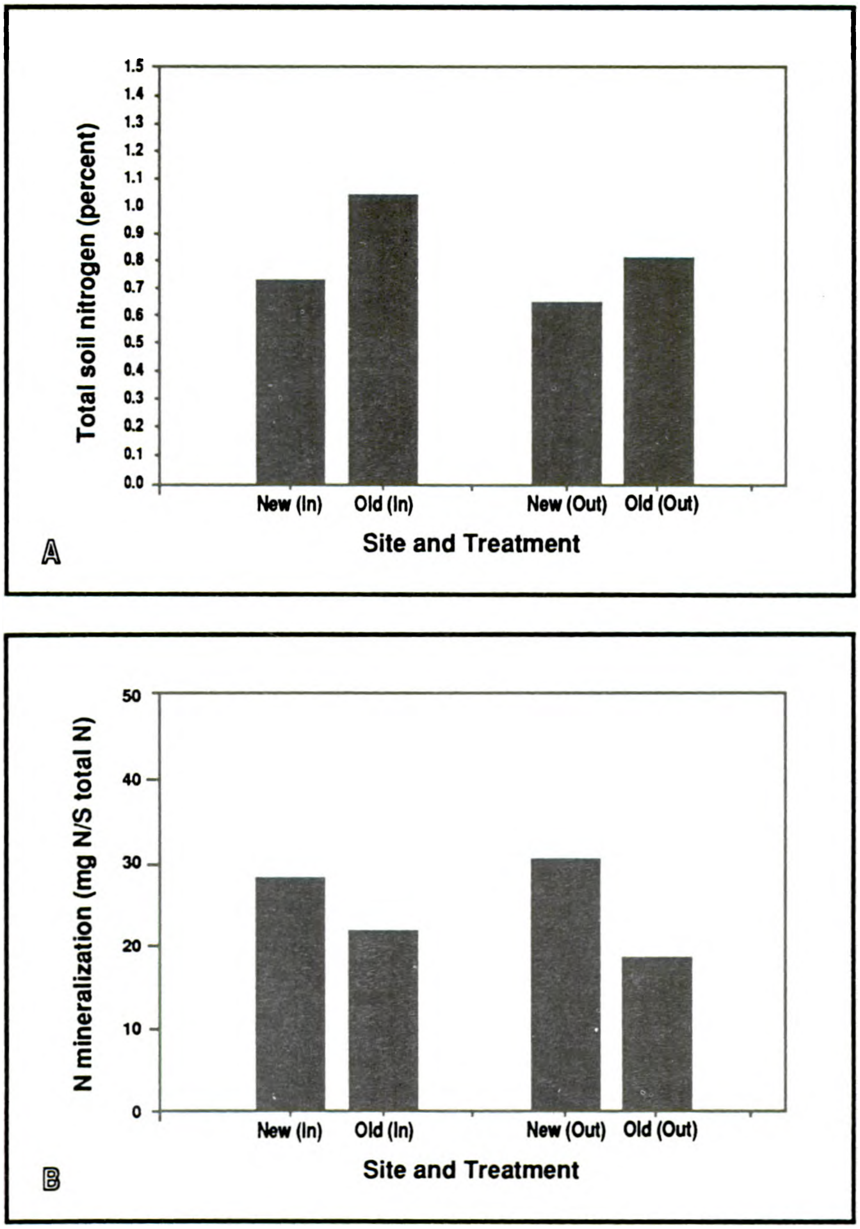

Figure 16—Total soil nitrogen (A) and nitrogen availability (B) in new and old moose exclosure sites, 1987.

Synthesis

M.D. Bryant and R.C. Wissmar[1]

The geomorphology of the Copper River Delta wetlands provides the framework for the ecological structure of the wetlands. Three agents seem to have the greatest influence on the geomorphology of the area: glacier and riverine sediments, tectonic uplift, and tidal action. Of these, glaciers and tectonic uplift are contributing new exposed surface area. Tidal action—including effects of the off-shore current—also plays a role in the construction of off-shore islands. One of the most important factors in the formation of the Copper River Delta are off-shore barrier islands and a relatively high sediment load, contributed primarily by the numerous glaciers feeding into the Copper River and nearby coastal rivers, such as the lower reaches of the Eyak River.

Glaciers provide the main source of inorganic material to the streams. Differential sedimentation by particle size determines the substrate of the slough and distributary channels dissecting the wetlands; sediment disposition is further influenced by tidal action in the lower wetlands. Sediment is deposited and spread away from main channels by tidal flooding. Wetland vegetation traps sediment, which results in the formation of levees. As levees become higher, vegetation changes and the channels stabilize. Vegetation along the levees may, in turn, contribute to the nutrient budget through organic carbon and nitrogen fixation by species such as *Myrica gale* and alder (*Alnus* spp.)

Deposition of fine glacial "flour" through both glacial and tidal action may contribute to the apparent low productivity in some of the sloughs along the edges of the mountains and the sloughs east of the Martin River Slough. In addition, the sloughs are fed by snowmelt and rain on the mountains that flows through scoured rock. These areas show very little biological activity, with low phytoplankton diversity and density, few or no macrophytes, few invertebrates, and no juvenile salmonids. Other factors possibly contributing to low biological productivity are low water temperature and limited drainage areas.

The circular and meandering morphology of the interbasin slough channels in the central area of the wetlands—east of Mountain Slough up to the Copper River—exposes a large surface that will collect leachates from the wetlands and the perched ponds of the wetlands and will result in greater input of nutrients. In addition, surface heating of the surrounding wetlands and shallow ponds will increase temperatures that will increase biological activity. Beaver activity has created a series of ponds, which act as a source and sink of nutrients in many of the sloughs and will provide organic input to the system. The results of this survey point to increasing productivity toward the middle areas of the wetlands. Greater abundance and diversity of phytoplankton and macrophytes were found in these areas, and salmonids were more productive in the interbasin habitats than other habitat types. Although the link from channel morphology to nutrient recycling to salmonid populations is intuitively appealing, the mechanisms controlling the energy flow and the carrying capacities of these systems remain undefined.

The forested and upland habitats may be controlled by a different set of conditions. These systems, represented by Meadowbrook Creek, may reflect processes commonly found in

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forested streams: organic inputs from wood debris, limited instream primary production, and channel morphology controlled by wood inputs. These areas with relatively stable gravel bars and coarse substrate seem to provide the primary spawning areas for coho and sockeye salmon. Salmon fry from these areas probably migrate downstream to the slough and pond habitats in the lower wetlands.

In contrast, productivity in the habitats of the wetlands is influenced by the tidal flux with primary production mediated by marine influence. The marine influence diminishes in the old marsh, but primary production likely is the major source of biological production in the system. The higher levels of methane production suggest that anaerobic bacteria are important biological agents in the ponds throughout the wetlands.

Research and Management Recommendations

Manipulation of habitat with the objective of increasing salmonid production must be based on an understanding of the physical and biological processes of the system. Research effort should be directed to understanding how these processes are related in space and time. Discrete habitats identified in this survey are connected and interact to contribute to the character and productivity of the system. Beaver ponds, for example, have a profound influence on the landscape and on the sloughs of the wetlands and alter the productivity and morphology of the sloughs throughout the old marsh. The terrestrial environments contribute to the aquatic nutrient flow into the aquatic system as well as to the physical structure of the ecosystem. These interactions are further linked through time, both seasonally and annually, and successional stages may span centuries. The linkages, successional stages, and gradients of the habitat and landscape are part of the structure and function of the Copper River Delta and in turn influence the survival and production of fish and wildlife.

Critical research needs include the following topics:

1. How habitat management and enhancement projects for fish and wildlife can be redefined in terms of habitat structure and function within a landscape perspective. This knowledge currently is inadequate for proper management of the wetlands.

2. Methods to define, identify, and inventory the aquatic habitats of the Copper River Delta. Research should be directed by understanding the ecosystem processes, linkages, and successional stages.

Future study topics should:

1. Define the use of habitat by juvenile salmonids by season and over habitat gradients and include important species-specific factors such as growth and survival.

2. Document the geomorphic and hydrologic processes that determine the development and evolution of channels and ponds and the succession of the surrounding flood-plain vegetation and soils.

3. Establish the factors that control and limit primary and secondary trophic-level production, and determine the relations and linkages among nutrients, primary production, and consumers—both herbivores and predators.

Development of studies within these broad topic areas should provide the basis for sound management of the aquatic ecosystem of the Copper River Delta.

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In July 1987, a 2-week synoptic survey was conducted on the wetlands of the Copper River Delta by an interdisciplinary team of scientists. Disciplines included geomorphology, limnology—water chemistry and nutrients, plankton and macroinvertebrates, anadromous fish populations, and wetland plant ecology. The purpose of this report is to present a summary of the findings of each group, preliminary conclusions, and recommendations for further research. The results are limited in scope due to the limited observation time and the single point in the year—midsummer. Because all observations were done concurrently at similar sites, the results are linked in time and place. Trends in productivity across the wetlands appear in the results. High rates of methane production indicated higher levels of production in ponds and beaver sloughs than expected as well as anaerobic decomposition processes in the ponds. Greater diversity in both phytoplankton and zooplankton species were observed in the ponds and sloughs than in glacial streams. Ponds, sloughs and woodland streams were found to support the highest densities of juvenile coho salmon. Sockeye salmon were observed in the wetland and intertidal sloughs. The results indicated that complex interactions occur among geomorphology, plant succession, nutrient cycles, and hydrologic processes affecting biological production. Research should address ecosystem processes, linkages throughout the trophic structure, and successional stages within the wetlands.

Keywords: Wetlands, aquatic habitat, Copper River Delta, salmonid habitat, wetlands research, water chemistry, aquatic biology.

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