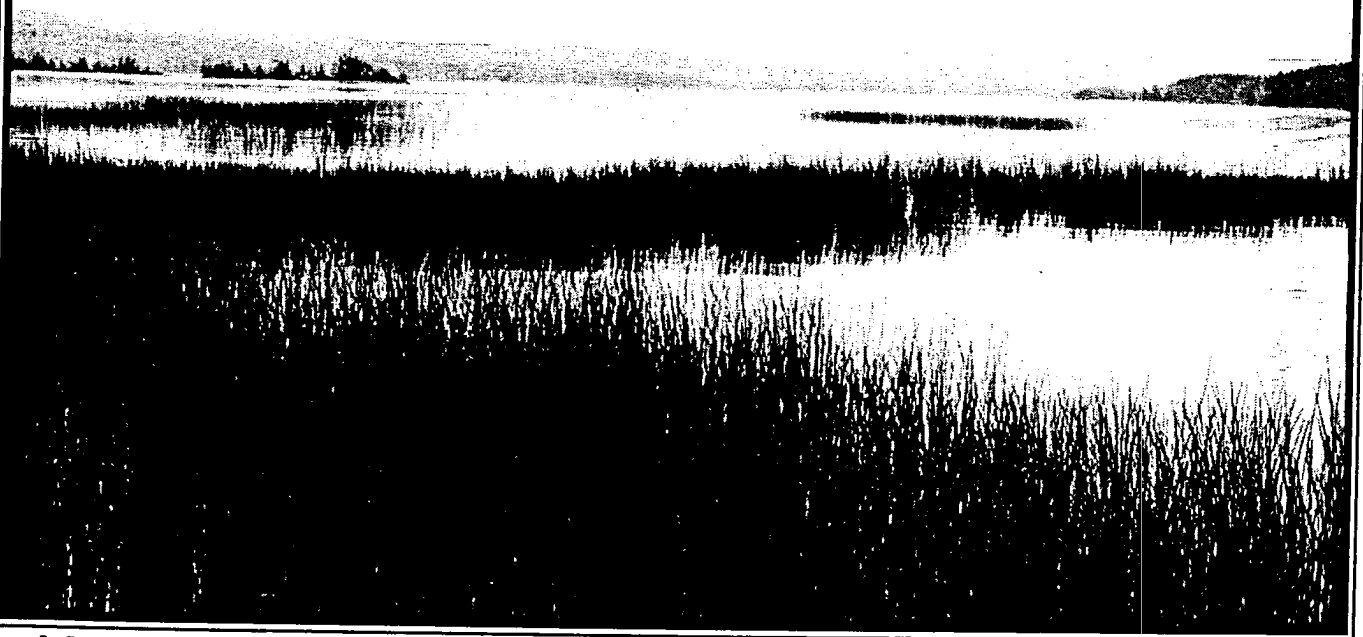


Great Lakes Coastal Wetlands

Abiotic and Floristic Characterization

Michigan Natural
Features Inventory

1998



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**Great Lakes Coastal Wetlands:
Abiotic and Floristic Characterization**

A Summary of Reports Prepared for Michigan Natural Features Inventory

**Leah D. Minc,
Data Analyst**

and

**Dennis A. Albert,
Ecologist, MNFI**

Michigan Natural Features Inventory

Mason Building
P.O. Box 30444
Lansing, MI 48909-7944
(517) 373-1552
FAX (517) 373-6705

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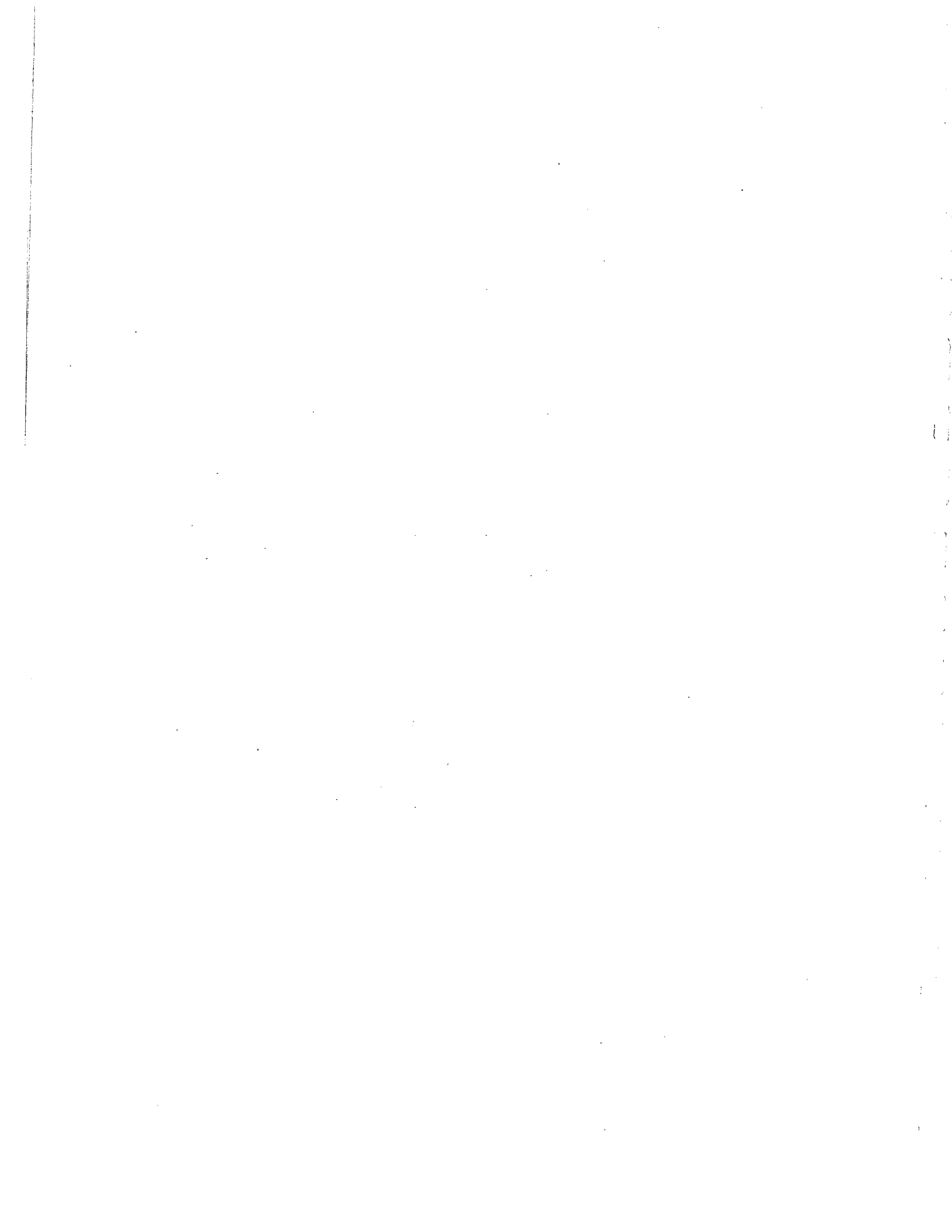
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I. Introduction

Great Lakes coastal wetlands occur along the Great Lakes shoreline proper and in portions of tributary rivers and streams that are directly affected by Great Lakes water regimes. These wetlands form a transition between the Great Lakes and adjacent terrestrial uplands, and are influenced by both. Over the past two decades, a wealth of detailed information has been generated on these systems, ranging from a comprehensive inventory of wetlands along the U.S. Great Lakes shoreline (Herdendorf et al. 1981a-1981f), to detailed studies on the hydrology, sediment history, water chemistry, and flora of one or a few sites (e.g. Krieger 1989). To date, however, there has been little emphasis on regional variability within these wetlands and how that variability relates to environmental parameters.

This study addresses that gap, by providing a regional perspective on the abiotic variability and associated vegetation characteristics of herbaceous coastal wetlands of the Great Lakes shoreline. This study is based on field sampling conducted in over 110 coastal wetlands in Minnesota, Wisconsin, Michigan, Ohio, Pennsylvania, and New York by Michigan Natural Features Inventory (MNFI) between 1987 and 1994 (Albert et al. 1987, 1988, 1989; Minc 1996a, 1996b, 1997a, 1997b, 1997c). The goal of MNFI's project was to identify vegetatively distinct wetland types, and to develop a wetland classification for the Great Lakes coastline that links floristic variability to controlling abiotic factors.

II. Methods

Floristic variability among coastal wetlands can be characterized in terms of specific vegetative zones. Moving from deeper water to the shore, typical zonation includes (1) the **Submergent Marsh** containing submergent and/or floating vegetation; (2) **Emergent Marsh** characterized by shallow water or saturated soils, and typically dominated by bulrushes, cat-tails, and other emergent species, but also containing submergent and/or floating vegetation; and (3) a narrow but diverse **Shoreline or Strand Zone**, at or just above the water line where seasonal water-level fluctuations and waves cause erosion, usually dominated by annual herbs. Inland from the water's edge, additional zones can be identified: (4) the **Herbaceous or Wet Meadow** zone characterized by saturated or periodically flooded soils, and dominated by sedges, grasses, and other herbs; and (5) the **Shrub Swamp** and (6) **Swamp Forest** zones, both characterized by periodic standing water, and dominated by woody species adapted to a variety of flooding regimes. Not all zones are present or well-developed in every wetland.

In order to provide baseline data on both the biotic and abiotic components of selected coastal wetlands, sampling transects were established to include the full range of vegetation zones present, extending from the upland boundary lakeward to water depths of approximately 2 m. At 10-20 m intervals along the transect, the cover value for each species present was recorded, along with data on substrate, organics, and water depth. Species cover values were then summed by vegetation zone and their mean cover values computed, in order to generalize species behavior throughout the zone as a whole. These data were then integrated with regional information on bedrock characteristics, glacial landform, soils, topography, shoreline configuration, and water clarity.

The present study concentrates on patterns of species co-occurrence and distribution in three wetland zones (emergent marsh, herbaceous/wet meadow, and shrub swamp), and the results were combined into a final, synthetic classification of Great Lakes coastal wetlands. Data for these analyses were taken along 130 transects representing 102 marshes sampled in the field

(Fig. 1).¹ The vegetative analyses had two specific goals: first, to define groups of transects with similar species composition that represent distinct wetland types; and second, to clarify the site factors controlling species distribution and hence the occurrence of the different wetland types.

The identification of distinctive patterns of species co-occurrence relied heavily on TWINSPLAN or Two-Way Indicator Species Analysis, a polythetic divisive method of classification of samples based on the differential occurrence or abundance of one or more indicator species (Hill 1973, 1979). This analysis results in an ordered two-way table that groups similar samples together and similar species together, thereby displaying the significant divisions within the data set. Site factors determining species distributions were assessed through a variety of methods. Key aspects of spatial or geographic patterning were identified through regional plots of species density. Species preferences for specific types of substrate and shoreline configuration were clarified through maps, tables, descriptive statistics, and bar plots, where appropriate.

III. Major Findings: Abiotic Factors

Our analyses found that patterns of species co-occurrence and distributions are determined by multiple abiotic factors, including aquatic system, Great Lakes water level fluctuations, surficial bedrock, glacial landform, climate, and land use. These factors operate at different scales (from regional to local), and the importance of any one factor varies markedly across the region.

A. Aquatic System

Four major aquatic systems, defined largely on water flow characteristics and residence time (Sly and Busch 1992), are applicable to the Great Lakes Basin; each has a different potential influence on associated coastal wetlands.

Lacustrine systems are controlled directly by waters of the Great Lakes, and involve wetlands of the Great Lakes shoreline strongly affected by littoral (longshore) currents and storm-driven wave action. Lacustrine habitats generally experience the greatest exposure to wind and wave action and to ice scour, the primary agents responsible for shore erosion and redeposition of sediments.

Connecting channels refer to the major rivers linking the Great Lakes, including the St. Marys, Detroit, St. Clair, Niagara, and St. Lawrence rivers. Connecting channels are characterized by a large flow, but seasonally stable hydrology; their shallowness and current result in earlier spring warming and better oxygenation than in other aquatic systems. All the connecting channels are modified, primarily to accommodate shipping.

Riverine aquatic systems refer to smaller rivers tributary to the Great Lakes whose water quality, flow rate, and sediment load are controlled in large part by their individual drainages. Tributary rivers have a much lower volume, but seasonally more variable flow than connecting channels, and are influenced by the Great Lakes near their mouth.

Lacustrine or freshwater estuaries, formed where some tributary rivers enter the lakes, are aquatic systems distinctive to the Great Lakes, and represent a zone of transition from stream to lake within which water level, sedimentation, erosion, and biological processes are controlled by fluctuations in lake level.

¹Transects excluded from the study typically had high levels of human disturbance.

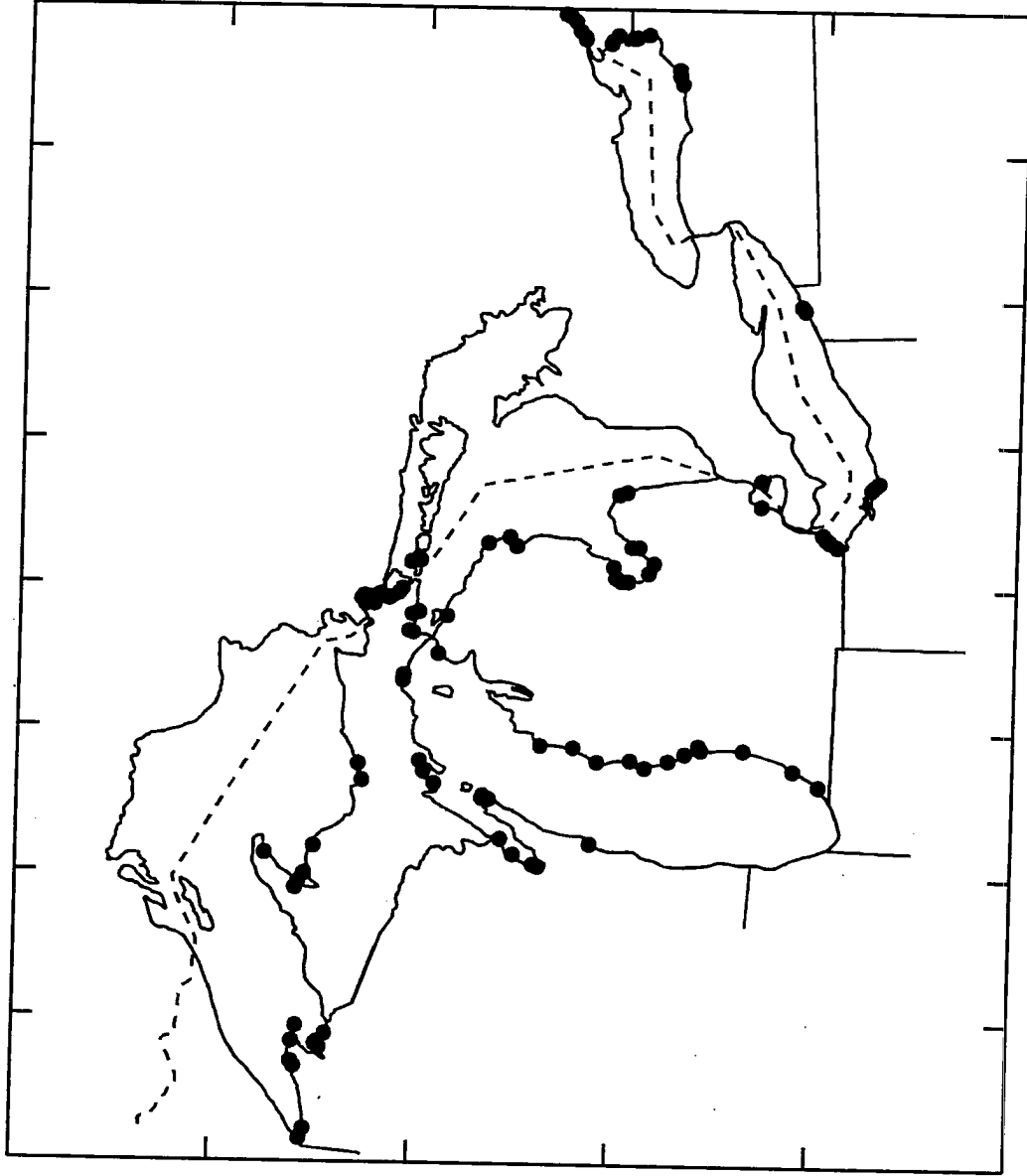


Figure 1. Distribution of Great Lakes coastal wetlands evaluated in this study.



B. Fluctuations in Great Lakes Water Levels

The preceding aquatic systems are influenced, to differing degrees, by fluctuations in Great Lakes water levels. These fluctuations occur over three temporal scales: (1) **short-term fluctuations** in water level caused by persistent winds and/or differences in barometric pressure; (2) **seasonal fluctuations** reflecting the annual hydrologic cycle in the Great Lakes basin; and (3) **interannual fluctuations** in lake level as a result of variable precipitation and evaporation within their drainage basins.

All of these scales contribute to the dynamic character of coastal wetlands, although interannual fluctuations impose the greatest stress. These extreme lake-level fluctuations can range from 3.5 to 6.5 feet (1.3-2.5 m), and occur with no regular periodicity. In general, as water levels rise and fall, vegetation communities experience a locational shift: landward during high-water years, and lakeward during low-water years. However, fluctuating lake levels effect not only a change in water depth, but a broad range of associated stresses to which plants must respond, including changes in water current, wave action, turbidity (clarity or light penetration), nutrient content or availability, alkalinity, and temperature, as well as ice scour and sediment displacement. Since individual species display different tolerance limits along one or more of these dimensions, species composition can also change dramatically within a zone.

Conversely, the absence or dampening of natural lake-level fluctuations alters species composition as well. Coastal wetland systems are adapted to and require periodic inundation. Where water-level regulation has significantly reduced the occurrence of extreme high and low water levels, disruption of the natural cycle favors species intolerant of water-depth change and associated stresses, and/or excludes species requiring periodic exposure of fertile substrates, potentially leading to a reduction of species diversity. The dominance of cat-tails in many Lake Ontario marshes suggests a trend toward reduced species diversity following a reduction in the amplitude of natural water-level fluctuations (Wilcox et al. 1993).

C. Surficial Bedrock

The physical and chemical characteristics of different surficial bedrock types can affect both wetland location and species composition. The major bedrock distinction in the Great Lakes Basin is between igneous and metamorphic bedrock (including granite, basalt, and rhyolite) of the Precambrian period, and younger (Paleozoic) sedimentary bedrock (including sandstone, shale, limestone, and dolomite). Igneous and metamorphic bedrocks form the north shore of Lake Superior and Georgian Bay, and line much of the St. Lawrence River; they are locally present along the southern shore of western Lake Superior as well, where they co-occur with younger sedimentary rock, primarily sandstone. In contrast, the softer, sedimentary bedrock types underlie Lakes Michigan, Huron, St. Clair, Erie, and Ontario.

The **physical structure** of bedrock type limits the distribution of coastal wetlands at a regional scale. The rugged Lake Superior shoreline of sandstone, igneous, and metamorphic rock lacks the shallow protected waters and fine-textured substrates that support broad coastal wetlands; coastal wetlands exist only behind protective barrier beaches or are localized at stream mouths. In contrast, the horizontally-deposited marine and near-shore sedimentary rock which underlies Lakes Michigan, Huron, St. Clair, Erie, and Ontario, provides broad zones of shallow water and fine-textured substrates for marsh development.

Where bedrock is at or near the surface, **bedrock chemistry** affects wetland species composition. Soils derived from much of the Precambrian crystalline bedrock are generally acid

and favor the development of poor fen or bog communities. In contrast, soils derived from marine deposits, including shale and marine limestone, dolomite, and evaporites, are typically more calcareous (less acid), nutrient- and moisture-rich loams and clays; where these bedrock types are at or near the surface, their alkalinity creates the preferred habitat for calciphilic species.

D. Glacial Landform

Today, glacial landforms, in combination with recent longshore transport processes, create the prevalent physiographic features along much of the Great Lakes shoreline. Their characteristic differences in substrate, soils, slope, and drainage conditions largely determine both natural shoreline configuration and sediment composition. These, in turn, generate distinctive contexts for wetland development that vary in their exposure and resilience to lake stresses, and in their floristic composition.

The major morphometric or site types represented in the wetland systems inventoried for this study are presented in Table 1 (see also Plates 1-4). Among freshwater systems, many of these geomorphic features are unique to the Great Lakes coasts, and are typically overlooked in national wetland classification schemes. However, the importance of these features for classifying Great Lakes coastal wetlands is clear. As Herdendorf et al. (1981a:110) state it, "the occurrence, distribution, and diversity of [Great Lakes] coastal wetlands is, in part, determined by the morphology of the coast. Perhaps in no other geographic environment is the relationship between landforms and vegetation so evident".

Several of these morphometric types can co-occur; other types are gradational. The site types are not mutually exclusive categories, rather they illustrate how the convergence of landform and lake create and influence wetland and aquatic habitats. Further, since the floristic diversity of a wetland is dependent on the diversity of wetland habitats, the variety of morphometric types represented is significant for understanding the vegetational characteristics of a site.

E. Climate

Regional patterns of climatic variability within the Great Lakes Basin are largely determined by latitude, with the modifying influence of the lakes (i.e. lake effect) operating at a more local level (Derecki 1976; Eichenlaub et al. 1990). The strong latitudinal gradient, from southern Lake Erie to northern Lake Superior, creates marked differences in length of growing season and annual input of solar energy across the region. These differences, in turn, are reflected in the regional distributions of a number of species common to Great Lakes wetlands.

While most aquatic macrophytes are widely distributed, species with known southern affinities make their appearance, as do those of the boreal forest. Lake Erie wetlands, for example, are rich in southern marsh species at the northern edge of their range which rarely occur along the other Great Lakes; a southern wet-prairie floristic element is apparent there as well (Stuckey 1989; Keddy and Reznicek 1985, 1986). Both of these southern floras differ significantly from the complex of boreal, subarctic, and arctic species found in the northern portions of Lakes Huron, Michigan, and Superior. Other species common to Great Lakes coastal wetlands reveal regional concentrations corresponding to a North-South gradient; these are species with wide distributions which achieve a greater density toward either the northern or southern edge of the Great Lakes Basin (Minc 1997c).

Table 1

Site Types for Great Lakes Coastal Wetlands

Aquatic Context	Site Type	Definition	Landform Context	Wetland Development
Lacustrine	Open embayment. <i>Plates 1a & 1b.</i>	Embayment open to the lake, but in areas where shallow water depth and gently sloping bottom topography reduce wave height and energy.	Sand lakeplain. Clay lakeplain.	Shifting sediments and wave energy limit wetland development to a narrow fringe. Fine-textured substrates are ideal for aquatic macrophytes, resulting in continuous wet meadow and emergent marsh.
	Protected embayment. <i>Plate 1c.</i>	Deep indentation or embayment in upland shoreline that provides protection from wind and wave energy.	Bedrock, moraine ridges, or clay lakeplain.	Extensive emergent wetland development.
	Barrier-beach lagoon. <i>Plate 2.</i>	Sand and gravel deposition create a barrier bar across the mouth of an embayment resulting in the formation of a shallow pond or lagoon.	Sand accumulation over bedrock, till, or lakeplain.	Extensive shallow water emergent vegetation; composition reflects degree of connectivity with Great Lakes.
	Sand-spit embayment and Sand-spit swale. <i>Plate 3a.</i>	Sand spits projecting along the coast create and protect shallow embayments on their landward side. Large, compound sand spits may also completely enclose small swales.	Gently sloping and curving sections of shoreline where sand transport is not impeded.	Sheltered embayments allow for sediment accumulation and wetland development; sand spits are exposed shallow water sites with unstable sediments.

Lacustrine (continued)	Dune and swale complex. <i>Plate 3b.</i>	Low sand dunes or beach ridges alternate with swales.	Sand lakeplain.	Swales adjacent to lake may contain herbaceous wetlands and/or open water.
	Tombolo. <i>Plate 3c.</i>	Island connected to the mainland by a series of beach ridges	Sand accumulation over bedrock.	Enclosed lagoons can contain a dense growth of aquatic vegetation; embayment leeward of tombolo may contain a fringe of emergent and submergent vegetation.
	Channel-side wetland.	Stream-side site fronting the main channels of connecting river and exposed to current and wave action.	Diverse contexts, including glacial lakeplain and till plain.	Vegetation is frequently limited to a thin fringe paralleling the shore.
Connecting Channel & Riverine	Channel embayment.	Embayment along connecting river channels which provide some protection from erosive elements.		Extensive monotypic wetland development can occur.
	Delta. <i>Plate 4a.</i>	Stream sediments are deposited and accumulate at the mouth of a river creating multiple shallow channels, low islands, and abandoned meanders.	Areas of low gradient flow with weak nearshore currents; glacial lakeplain.	Extensive diverse wetland development can occur.
Estuarine	Open estuary. <i>Plate 4b.</i>	Drowned river mouth displaying open, branching inlet form.	Sand lakeplain or till plain.	Protected, fertile wetland habitat that may extend inland for several miles.
	Barred estuary. <i>Plate 4c.</i>	Drowned river mouth with partial barrier bar or dune across the mouth.		

F. Human Land Use and Anthropogenic Stress

Differences in land use -- whether **urban, agricultural, or forested** -- create regional differences in the extent and quality of wetlands, as well as in their species composition. To a large extent, land use is a composite variable reflecting climate, physiography, and soils. The **tension zone**, a rough climatic boundary separating the forested north from the more agricultural south, closely follows regional differences in summer mean daily air temperature. Urban development, in contrast, reflects the early location of good harbors and the distribution of natural resources such as timber and mineral ores.

Both urban and agricultural development have resulted in severe degradation and loss of coastal marshes through pollution, land management, and ecosystem alteration:

- **Urban development**
 - Armoring of the shoreline and dredging of channels to create harbors has resulted in marsh elimination.
 - Dumping of waste materials such as sawdust and sewage, and a wide variety of chemicals has mechanically and chemically altered the shallow-water marsh environment, increasing turbidity, reducing oxygen concentrations, and altering the pH.
 - Shipping traffic has mechanically eroded shoreline vegetation.
 - Water-level control of the Great Lakes and connecting rivers has altered natural wetland dynamics.
- **Agriculture**
 - Drainage has eliminated large areas of marshes and coastal wetlands.
 - Sedimentation has greatly increased turbidity, eliminating submergent species requiring clear water.
 - Nutrient loading has locally reduced oxygen levels, prompted algal blooms, and led to the dominance of high-nutrient tolerant species such as cat-tails.
 - Heavy agricultural sedimentation has led to the deposition of rich organic mud in the wet meadows and along the shoreline, favoring the dominance of early successional species.
 - Introduction of exotic plants has altered macrophyte species composition.

III. Major Findings: Vegetation Analyses

The preceding abiotic variables (including aquatic system, water level fluctuations, surficial bedrock, glacial landform, climate, and land use) combine to determine the distribution, as well as the morphology, species composition, and quality, of Great Lakes coastal wetlands. The final, synthetic classification of Great Lakes coastal wetlands (based on both abiotic and vegetation analyses) identified nine groups, each with distinctive floral characteristics and a restricted geographic distribution (Table 2). Vegetation zonation and key species (i.e. species showing a preferential distribution relative to each group) are discussed below.

(1) Lake Superior Poor Fen. This group contains most of the wetlands sampled along the Lake Superior shoreline. These wetlands occupy sheltered sites, including barrier-beach lagoons, estuaries, and tributary river deltas, since marshes cannot develop along unprotected stretches of Lake Superior's harsh shoreline. These sites are characterized by fairly acidic, sandy soils and an extreme northern climate. As a result, organic decomposition is retarded and deep organic soils develop.

Characteristic vegetation includes northern poor fen in the herbaceous zone grading into poor shrub fen at the inland wetland periphery; the poor fen is typically the most extensive zone within Lake Superior wetlands. Species showing strong preferences for this habitat include *Sphagna* spp., the forbs *Sarracenia purpurea* (pitcher-plant), *Menyanthes trifoliata* (buckbean), *Rhynchospora alba* (beak-rush), *Triadenum fraseri* (marsh St. John's-wort), *Pogonia ophioglossoides* (rose pogonia), and the shrubs *Chamaedaphne calyculata* (leatherleaf), *Andromeda glaucophylla* (bog rosemary), *Myrica gale* (sweet gale), *Vaccinium macrocarpon* (large cranberry) and *V. oxycoccus* (small cranberry). Continuity in species composition for northern poor fen is strong across a considerable range of lake levels (Minc 1997b), although extreme high lake levels reduce the abundance of some characteristic species, including *Sphagnum* spp. and *Chamaedaphne calyculata*.

The emergent zone, typically only a narrow fringe, contains species associated with clear, well-aerated waters, including a low-density mix of *Eleocharis smallii* (spike-rush), *Sparganium fluctuans* (bur-reed), and the bulrush *Scirpus subterminalis*. Common floating-leaved species include *Nuphar variegata* (yellow pond-lily), *Brasenia schreberi* (water shield), and *Megalodonta beckii* (water-marigold), while the pondweed *Potamogeton gramineus* is the most frequently encountered submergent species.

(2) Northern Rich Fen. This group comprises coastal sites concentrated near the Straits of Mackinac and located on marly substrates. Most of these sites occupy embayments of the open, sandy shoreline where limestone bedrock or cobble is at or near the surface. These sites have calcareous soils (with a pH as high as 8.2), resulting either from calcareous substrates, water flow off adjacent limestone bedrock or limestone-rich till, or algal precipitation of calcium carbonate in the relatively warm, carbonate saturated waters. The result is the formation of distinctive "marly flats" and an associated complex of calciphile plant species.

The calciphiles *Chara* sp. (muskgrass) and *Eleocharis rostellata* (spike-rush) frequently dominate the emergent zones, along with *Scirpus acutus* (hardstem bulrush); overall species diversity is low. The herbaceous zone -- the most distinctive and diagnostic zone -- is consistently a northern rich fen. *Calamagrostis canadensis* (blue-joint grass) can dominate, but the calciphiles *Carex viridula* (sedge) and *Lobelia kalmii* (Kalm's lobelia) are key species for this group. Other species indicative of rich fen along the Great Lakes shoreline include *Cladium mariscoides* (twig-rush), *Potentilla anserina* (silverweed), *Panicum lindheimeri* (panic grass), *Triglochin maritimum* (common bog arrow-grass), and *Hypericum kalmianum* (Kalm's St. John's-wort). Common woody species of the associated rich shrub fen include *Myrica gale* and *Potentilla fruticosa* (shrubby cinquefoil), while *Larix laricina* (larch) and *Salix pedicellaris* (bog willow) are consistently present, but in low numbers. This characteristic suite of calciphiles make the Northern Rich Fen type readily recognizable across a range of lake-level fluctuations (Minc 1997b).

(3) Northern Great Lakes Marsh. This group includes all marshes along the St. Marys River, as well as circumneutral sites of Lake Superior and northern Lakes Michigan-Huron; it is the largest group of Great Lakes wetlands sampled. Marshes of this type occur on a diversity of glacial landforms and substrates, including clay lakeplain, sand lakeplain, and sandy ground moraine. Sites types vary: Lake Superior northern marshes typically inhabit open water and stream margins within estuarine sites, often within a much larger poor fen; those of northern Lakes Michigan-Huron are typically found in relatively protected coastal embayments. The largest group of sites, however, is the channel-side wetlands and embayments along the St. Marys River.

The open emergent zone features low densities of *Scirpus acutus* (hardstem bulrush) and *Eleocharis smallii* (spike-rush), along with *Scirpus subterminalis* (bulrush), *Equisetum fluviatile*

(water horsetail), *Najas flexilis* (slender naiad), and *Sparganium eurycarpum* (common bur-reed). The submergent pondweeds *Potamogeton gramineus* and *P. natans* are common occurrences in this zone as well. The herbaceous zone is consistently a northern wet meadow dominated by *Calamagrostis canadensis* (blue-joint grass), and the sedges *Carex stricta* and *C. lacustris*; key forbs include *Campanula aparinoides* (marsh bell-flower) and *Potentilla palustris* (marsh cinquefoil).

A narrow band of northern shrub meadow, often only 10-20 meters wide, borders many of these wetlands. Shrubby species strongly preferential to this zone include *Spiraea alba* (meadowsweet) and *Salix petiolaris* (meadow willow), but other wide-spread woody species are found here as well, primarily *Alnus rugosa* (speckled alder) and *Myrica gale*; *Calamagrostis canadensis*, *Carex stricta*, *C. lacustris*, and *Potentilla palustris* remain dominant as in the adjacent wet meadow zone.

(4) Green Bay Disturbed Marsh. This Lake Michigan group contains a small number of relatively well-protected sites, including deltaic channels, estuarine channels, and sheltered sand-spit embayments, primarily within Green Bay, WI. These sites are located near the **tension zone** and display both northern and southern vegetation characteristics. In general, the emergent zones of these sites contain a more southern flora high in floating species, while their wet meadow zones span the north-south division. These sites also share a highly disturbed habitat. The adjacent flat, poorly drained clay lakeplain has been intensively farmed with row crops, and waters of Green Bay are generally characterized as quite turbid, owing both to erosion from agricultural activities and to industrial and urban pollution.

Emergent zone dominants are species associated with quiet, nutrient-rich waters, and typically more abundant in the southern Great Lakes. Key species include *Ceratophyllum demersum* (coontail), *Elodea canadensis* (common waterweed), *Lemna minor* (small duckweed), and *Spirodela polyrhiza* (great duckweed), along with the widespread *Nymphaea odorata* (sweet-scented waterlily) and *Sagittaria latifolia* (common arrowhead). The herbaceous zone is a wet meadow in which *Calamagrostis canadensis* is clearly the dominant, while both *Carex stricta* and *C. lacustris* are present in low levels. Wet meadow species more characteristic of the south include *Impatiens capensis* (spotted touch-me-not) and *Typha angustifolia* (narrow-leaved cat-tail), as well as the exotics *Lythrum salicaria* (purple loosestrife), *Phragmites australis* (giant bulrush), and *Phalaris arundinacea* (reed canary grass). A distinct shrub zone was seldom encountered in sampling transects, due to heavy disturbance in the upland portion of the landscape.

Owing to the relatively flat topography, fluctuations in Lake Michigan's water level considerably alter the size of these coastal wetlands as well as their species composition (Harris et al. 1977). Receding high waters expose substantial portions of sandy beach and open mud flats, which are quickly colonized by dense stands of *Scirpus validus* (softstem bulrush), *Bidens cernuus* (nodding bur-marigold), and one or more species of *Polygonum* (smartweed). Over a period of several years, these colonizing species decline and are replaced by a sedge meadow consisting primarily of *Carex* spp. and *Calamagrostis canadensis* (Harris et al. 1981).

(5) Lake Michigan Lacustrine Estuaries. This group consists of barred lacustrine estuaries of western Lower Michigan, generally south of the tension zone. All of the major rivers along this stretch have lacustrine estuaries at their mouths. Most are partially to largely barred by longshore sand transport, and many have artificially maintained channels to Lake Michigan. These estuarine systems can extend for a considerable distance inland, where the rivers occupy linear floodplains cut into surrounding glacial moraines and sand lakeplain. Sites of this group are well protected from wind and wave action, owing to their long, narrow configuration and partial separation from Lake Michigan. This protection results in deep accumulations of organic deposits (mucks and

peats) throughout the emergent and herbaceous vegetation zones; open stream channels are generally shallow and nutrient rich, owing to the input of fine sediments and the presence of deep underlying organic substrates.

In the emergent zone, *Nuphar advena* (yellow pond-lily) and *Peltandra virginica* (arrow-arum) are characteristic of these muck soils, while the large cover values for the floating species *Ceratophyllum demersum* and the duckweeds *Spirodela polyrhiza*, *Lemna trisulca*, and *L. minor* reflect relatively protected waters with a high nutrient content. *Nymphaea odorata* has a widespread distribution, but can form particularly dense beds in these protected sites.

The herbaceous zone conforms to the southern wet meadow type. *Calamagrostis canadensis* is a frequent dominant, but key southern species include *Impatiens capensis*, *Rorippa palustris* (yellow cress), *Polygonum lapathifolium* (nodding smartweed), and *Leersia oryzoides* (cut grass). The southern shrub swamp is characterized by a mix of *Alnus rugosa*, *Cornus stolonifera* (red-osier dogwood), and *Fraxinus pennsylvanica* (red ash), but many of the above-mentioned herbaceous species occur throughout. In addition, *Osmunda regalis* (royal fern) is common here.

Vegetative response to changing lake levels in these estuarine sites appears to be largely a function of site morphometry (Minc 1997b). Steep confining banks appear to limit shallow water habitats during high water periods such that shallow water vegetation is largely eliminated. As a result, high-water years are marked by a decrease in edge communities and shallow water emergents, and a concomitant increase in floating-leaved communities and associated duckweeds.

(6) Saginaw Bay Lakeplain Marsh. This group contains most sites from Saginaw Bay. Formed by a flat glacial lakeplain that slopes gently into Lake Huron, Saginaw Bay is very shallow with a thin veneer of sand over clay; the Wildfowl Bay Islands are extensive sand spits formed over local exposures of limestone bedrock. Wetland site types range from protected sand-spit embayments to open coastal embayments.

Wetlands in this group contain a mix of northern and southern species; this dual affinity may reflect the location of the climatic tension zone across Saginaw Bay. In addition, most sites contain ample floristic evidence of surrounding intensive agricultural land-use.

The emergent zone is generally a northern emergent marsh containing the key northern species *Scirpus acutus* and *Eleocharis smallii*, although not in great densities. However, excessive sedimentation appears to have excluded many submergent species typically found within a northern emergent marsh, including most pondweeds, which are generally intolerant of turbidity. Both *Scirpus americanus* (three-square bulrush) and the more southerly *S. validus* are frequently present as well, while *Typha angustifolia* and *Najas flexilis* are common co-dominants; floating species (such as the duckweeds) are only minimally present. Along more open stretches of the bay, *Scirpus americanus* can form a narrow, but dense fringe, apparently due to its greater tolerance of extreme wave action.

The herbaceous zone is typically a southern wet meadow with a high percentage of early successional and disturbance species. Typical colonizing species include *Bidens cernuus*, *Impatiens capensis*, *Rorippa palustris*, *Scirpus validus*, and *Polygonum lapathifolium*; common exotics include *Lythrum salicaria*, *Phragmites australis*, *Phalaris arundinacea*, and *Polygonum persicaria* (lady's thumb). The absence of a distinct shrub swamp zone for this group may reflect the intensity of land-use in this area, in which fertile lacustrine soils are farmed as close to Great Lakes coastal wetlands as possible.

In contrast to most other wetland types, the marshes of the Saginaw Bay lakeplain experience significant changes in the abundance and ubiquity of dominant species relative to lake-level fluctuations, particularly in the herbaceous zone (Minc 1997b). The gentle slope of the lakeplain, combined with the heavy deposition of fine sediments, creates the potential for extensive, fertile mud flats following dry-down and favors colonizing species adapted to the cyclical exposure of this habitat (including *Rorippa palustris*, *Bidens cernuus*, *Polygonum lapathifolium*, and *Scirpus validus*). In contrast, when lake levels remain at or below the mean, succession to a more typical wet meadow takes place, with an increased dominance of *Calamagrostis canadensis* and *Carex stricta* and a dramatic drop in the cover values of the colonizing species.

(7) Lake Erie-St. Clair Lakeplain Marsh. This group includes all marsh sites from the glacial lakeplain of Lake St. Clair and western Lake Erie. Although the lakeplain formerly supported extensive marsh and wet prairie communities, the predominant remaining wetlands are the lacustrine estuaries formed at the mouths of rivers drowned by the post-glacial rise in lake level. However, even the remaining marshes reflect high levels of agricultural disturbance characteristic of the fertile, flat lakeplain soils, along with heavy manipulation of the shoreline through diking and rip-rap.

All of the wetlands occupy fairly protected sites (estuaries, barrier-beach lagoons, or sand-spit swales); in addition, the Lake Erie sites enjoy the most moderate climate of the Great Lakes region. As a result, their emergent marshes feature a relatively southern flora, while herbaceous zones are typically a southern wet meadow with a high proportion of disturbance species.

Common species of the emergent zone include the floating duckweeds (*Lemna minor* and *Spirodela polyrhiza*), and the canopy-forming submergents *Ceratophyllum demersum* and *Elodea canadensis*, characteristic of quiet, turbid waters. The southern species *Nuphar advena* is common, while *Nelumbo lutea* (American lotus) attains very high densities at selected sites. *Sagittaria latifolia*, *Scirpus validus*, *Typha angustifolia*, and *T. x glauca* (hybrid cat-tail) are common edge species.

Herbaceous zones are a southern wet meadow dominated by *Calamagrostis canadensis*, along with *Phalaris arundinacea*, *Typha angustifolia*, and *Polygonum lapathifolium*. The standard suite of early successional species (*Bidens cernuus*, *Impatiens capensis*, *Rorippa palustris*) and common exotics (*Lythrum salicaria* and *Phragmites australis*) are present as well. As in the case for Saginaw Bay, the absence of a distinct shrub swamp zone often reflects the intensity of land-use in this area, in which fertile lacustrine soils are farmed as close to coastal wetlands as possible.

The St. Clair River delta is loosely joined with the St. Clair-Erie lakeplain group; however, the St. Clair "flats" is a unique site in the Great Lakes, and its vegetation differs significantly from sites of Saginaw Bay to the north and Lake Erie to the south. Emergent zone vegetation is more typical of northern, open marshes, perhaps owing to the flow of the river. Common early successional and exotic species were only minimally present in large portions of the wet meadow.

(8) Lake Ontario Lagoon Marshes. Wetland sites in eastern Lake Ontario make up this group; all but one are barrier-beach lagoons. These sites share a similar protected site type, a lake-level regime characterized by a dampening of natural extreme fluctuations, and an associated set of distinctive species in the emergent, herbaceous, and shrubby zones.

Two distinct shoreline areas contain barrier-beach lagoons. Along the southern shore of Lake Ontario, the lake truncates a field of N-S oriented drumlins; here, low barrier beaches (generally less than 3 m high) across intervening embayments have created a series of shallow lagoons, including the East Bay, Black Creek, and Sterling Creek sites. Similarly, along the eastern end of Lake Ontario, predominant wind and water currents have led to the accumulation of sands, creating a low shoreline characterized by numerous embayments with barrier beaches and sand dunes rising up to 30 m above the lake. The barrier beaches create a string of shallow lagoons and wetlands, including Deer Creek, Cranberry Pond, South Colwell Pond, and Lakeview Pond.

The emergent zones of this type feature very high densities of the canopy-forming submergent species, *Ceratophyllum demersum* and *Elodea canadensis*, along with the duckweeds *Spirodela polyrhiza* and *Lemna trisulca*. *Nuphar advena* and *Nymphaea odorata* are also common. All of these reflect the well-protected and nutrient-rich waters of the lagoons, although *Lemna trisulca* may be associated with cold, spring-fed streams. High densities of this last species are distinctive to the Lake Ontario and St. Lawrence sites, as is the prevalence of *Potamogeton zosteriformis* (flat-stemmed pondweed).

The herbaceous zone is a wet meadow in which *Typha angustifolia* typically dominates, along with *Calamagrostis canadensis* and *Thelypteris palustris* (marsh fern). Cat-tail is particularly sensitive to flooding; its dominance in Lake Ontario corresponds historically to the recent period of lake-level regulation. In contrast, species adapted to the cyclical exposure of shoreline mud flats are poorly represented in these sites.

The shrubby zones divide into two distinct types. Buttonbush thicket features a mix of *Decodon verticillata* (swamp loosestrife) and *Cephalanthus occidentalis* (buttonbush), along with *Alnus rugosa*; *Thelypteris palustris* and *Peltandra virginica* dominate mucky openings within the thickets. In contrast, poor shrub fen was encountered in areas of low water flow behind barriers, typically distant from the active stream channel. Here, poor fen shrubs (*Chamaedaphne calyculata*, *Myrica gale*, *Vaccinium macrocarpon*, and *Andromeda glaucophylla*) dominate, while *Sphagna* spp. and *Sarracenia purpurea* attain high cover values in the groundcover.

(9) St. Lawrence River Estuaries. This group contains wetland sites along the upper reaches of the St. Lawrence River where the river is strongly influenced by Lake Ontario. This stretch features numerous islands and bedrock knobs on the adjacent mainland shore which are the surface expression of the Frontenac Arch, where overlying limestone and sandstone formations have been removed by glacial scouring to reveal the irregular surface of the underlying Precambrian rock. The exposed bedrock is mostly pink, massive rock of granitic composition; most of the exposures are smoothly rounded by scouring ice.

The St. Lawrence wetland sites are typically estuarine. Small streams or rivers occupy apparent pre-glacial valleys cut through the rounded bedrock knobs and ridges which have been partially filled in by outwash and alluvial deposits to form fairly broad, flat basins. Extensive wetlands (up to 1 km wide) line the lower reaches of the streams for several kilometers inland as they flow through the basins; a narrow delta has formed at the mouth of some basins. The valley of Crooked Creek is one of the best examples of wetland development along this stretch of the St. Lawrence River (Herdendorf et al. 1981a:53), while those of nearby Chippewa and Cranberry creeks are also of considerable importance to fish and wildlife (Geis and Kee 1977).

As in the preceding group, the emergent zone is characterized by high densities of floating species, including *Utricularia vulgaris* (great bladderwort) and the duckweeds *Lemna trisulca* and *Spirodela polyrhiza*, along with the canopy-forming submergent species, *Ceratophyllum demersum*

and *Elodea canadensis*. Other submergents preferential to this group include *Potamogeton zosteriformis*, *P. friesii* (Fries's pondweed), and *Zizania aquatica* (wild rice). The exotic *Hydrocharis morsus-ranae* (frog's bit) is abundant. The herbaceous zone is a broad wet meadow zone with deep organic soils (often > 4 m), featuring *Typha angustifolia* along with *Calamagrostis canadensis* and *Thelypteris palustris*. Again, the dominance of cat-tail may reflect the reduction of natural lake-level fluctuations. However, *Impatiens capensis*, a species adapted to the cyclical exposure of shoreline mud flats is well represented in this group of sites.

The assignment of Great Lakes coastal wetland sites to the preceding groups is summarized in Table 2. For maps showing site locations, see Figures 2-6.



Table 2
Classification and Ranking of Great Lakes Coastal Wetlands

Marsh ^a	Aquatic System	State	Site Type	Location		Size ^b (ha)	Rank ^c
				Latitude	Longitude		
Lake Superior Poor Fen							
Fond du Lac *	Lake Superior	MN	Barred lacustrine estuary	47.08	91.68	40	BC
Bad River B *	Lake Superior	WI	Barrier-beach lagoon	46.92	90.34	1600	A
Bark Bay A&B	Lake Superior	WI	Barrier-beach lagoon	47.15	90.68	270	AB
Honest John	Lake Superior	WI	Barrier-beach lagoon	46.85	90.22	260	A
Raspberry Bay A *	Lake Superior	WI	Barrier-beach lagoon	47.18	90.33	60	AB
Siskewit Bay	Lake Superior	WI	Barrier-beach lagoon	47.18	90.61	100	B-C
Stockton Is.	Lake Superior	WI	Barrier-beach lagoon	47.14	90.12	90	A
Au Train	Lake Superior	MI	Barred lacustrine estuary	46.53	86.71	160	AB
Grand Island	Lake Superior	MI	Barrier-beach lagoon	46.57	86.48	50	A
Independence Lake	Lake Superior	MI	Barrier-beach lagoon	47.00	87.62	130	B-D
Lac la Belle	Lake Superior	MI	Barred lacustrine estuary	47.48	87.72	200	A
Pequaming	Lake Superior	MI	Barrier-beach lagoon	47.09	88.01	170	B
Portage R.	Lake Superior	MI	Open lacustrine estuary	47.15	88.12	275	B
Sturgeon R.	Lake Superior	MI	Tributary delta	47.17	88.20	445	B-D
Northern Rich Fen							
Big Shoal Cove	Lake Huron	MI	Embayment-Protected	45.99	83.64	80	B
Cheboygan	Lake Huron	MI	Embayment-Protected	45.71	84.42	115	A
El Cajon Bay	Lake Huron	MI	Embayment-Protected	45.10	83.32	180	A
Peck Bay	Lake Huron	MI	Embayment-Protected	46.00	84.36	30	A
Voight Bay	Lake Huron	MI	Embayment-Protected	45.99	84.37	50	A
Epoufette Bay	Lake Michigan	MI	Embayment-Open	46.13	85.25	53	B-D
Kenyon Bay	Lake Michigan	MI	Embayment-Protected	46.14	85.32	40	B
Waugoshance Pt.	Lake Michigan	MI	Sandspit swale	45.79	84.95	265	A-AB
Carp/Pine R. **	Lake Huron	MI	Embayment-Open	46.05	84.65	90	A
False Presque I. **	Lake Huron	MI	Barred lacustrine estuary	45.31	83.40	140	B
Mud Lake **	Lake Michigan	WI	Barrier-beach lagoon	45.26	86.96	110	A

Marsh*	Aquatic System	State	Site Type	Location		Size ^b (ha)	Rank ^c
				Latitude	Longitude		
Northern Great Lakes Marsh							
Fond du Lac	Lake Superior	MN	Barred lacustrine estuary	47.08	91.68	40	BC
Pokegama A & B	Lake Superior	WI	Open lacustrine estuary	47.04	91.54	80	B
Bad River Mouth	Lake Superior	WI	Barred lacustrine estuary	46.92	90.34	1600	A
Kakagon Slough	Lake Superior	WI	Barred lacustrine estuary	46.94	90.36	2500	A
Long Island	Lake Superior	WI	Sandspit swale	46.90	90.41	80	BC
Raspberry Bay B*	Lake Superior	WI	Barred lacustrine estuary	47.18	90.33	60	AB
Baie de Wasai	St. Marys R.	MI	Channel embayment	46.53	84.26	200	B
Churchville Pt.	St. Marys R.	MI	Channel-side wetland	46.39	84.12	65	CD
Gogomain R.	St. Marys R.	MI	Chan.-side wetland & Embay.	46.16	84.03	170	BC
Hog Island	St. Marys R.	MI	Chan.-side wetland & Embay.	46.56	84.18	32	CD
Hursley Creek	St. Marys R.	MI	Channel-side wetland	46.44	84.26	220	BC
Kemps Point	St. Marys R.	MI	Channel-side wetland	46.29	84.17	50	BC
Munuscong R.	St. Marys R.	MI	Channel embayment	46.20	84.10	700	A-D
Roach Point	St. Marys R.	MI	Channel embayment	46.20	84.10	155	AB
Sand Island	St. Marys R.	MI	Channel-side wetland	46.30	84.17	200	A-D
Shingle Bay	St. Marys R.	MI	Channel embayment	46.46	84.24	130	AB
Sugar Island	St. Marys R.	MI	Channel-side wetland	46.45	84.16	80	AB
Whipple Point	St. Marys R.	MI	Channel-side wetland	46.54	84.14	120	BC
Duck Bay	Lake Huron	MI	Embayment-Protected	46.00	84.36	100	A
Mackinac Bay	Lake Huron	MI	Embayment-Protected	46.06	84.40	125	B-D
Mismer Bay	Lake Huron	MI	Embayment-Open	46.05	84.40	67	B-C
Scott Point	Lake Huron	MI	Embayment-Open	46.08	83.67	65	B-C
Squaw Bay	Lake Huron	MI	Embayment-Open	45.03	83.44	290	B-C
St. Martins Bay	Lake Huron	MI	Embayment-Open	46.09	84.63	110	A-D
Tobico	Lake Huron	MI	Barrier-beach lagoon	43.68	83.79	525	C-D
Chippewa Pt.	Lake Michigan	MI	Embayment-Open	45.81	86.74	36	C-D
Indian Point	Lake Michigan	MI	Embayment-Open	45.92	86.57	53	BC
Little Fishdam R.	Lake Michigan	MI	Embayment-Open	45.96	86.44	73	BC
Mink River	Lake Michigan	WI	Open lacust. estuary & Delta	45.32	86.91	260	A

Marsh ^a	Aquatic System	State	Site Type	Location		Size ^b (ha)	Rank ^c
				Latitude	Longitude		
Green Bay Disturbed Marsh							
Dead Horse Bay	Lake Michigan	WI	Sandspit embayment	44.75	87.88	128	C
Little Tail Pt.	Lake Michigan	WI	Sandspit embayment	44.80	87.85	84	C
Oconto River	Lake Michigan	WI	Tributary delta	45.00	87.71	700	B-C
Peshigo River	Lake Michigan	WI	Tributary delta	45.13	87.50	1100	B-C
West Twin River	Lake Michigan	WI	Barred lacustrine estuary	44.23	87.56	200	B-D
W. Lake Michigan Estuaries							
Bar Lake	Lake Michigan	MI	Barrier-beach lagoon	44.41	86.23	105	B
Betsie River	Lake Michigan	MI	Barred lacustrine estuary	44.74	86.21	40	C
Big Sable R.	Lake Michigan	MI	Barred lacustrine estuary	44.17	86.43	90	CD
Galien River	Lake Michigan	MI	Barred lacustrine estuary	41.94	86.73	130	B
Kalamazoo R.	Lake Michigan	MI	Barred lacustrine estuary	42.70	86.25	425	AB
Muskegon R.	Lake Michigan	MI	Barred lacustrine estuary	43.29	86.31	385	CD-D
Paw Paw R.	Lake Michigan	MI	Barred lacustrine estuary	42.20	86.52	65	ABC
Pentwater R.	Lake Michigan	MI	Barred lacustrine estuary	43.83	86.41	97	BC
Pottawattomi Bayou	Lake Michigan	MI	Barred lacustrine estuary	43.12	86.25	50	AB
S. Lloyd Is.	Lake Michigan	MI	Barred lacustrine estuary	43.15	86.19	34	C
Stoney Creek	Lake Michigan	MI	Barred lacustrine estuary	43.69	86.50	81	BC-C
White River	Lake Michigan	MI	Barred lacustrine estuary	43.45	86.41	485	BC
Saginaw Bay Lakeplain Marsh							
Coryeon Pt.	Lake Huron	MI	Embayment-Open	43.63	83.66	536	B-CD
Hardwood Pt.	Lake Huron	MI	Embayment-Open	43.92	82.68	60	CD
Pinconning A	Lake Huron	MI	Sandspit embayment	43.89	83.91	60	B
Pinconning B	Lake Huron	MI	Embayment-Open	43.89	83.91	60	B
Pine River	Lake Huron	MI	Embayment-Open	44.01	83.86	120	B-D
Saganing River	Lake Huron	MI	Embayment-Protected	43.96	83.91	20	C
Whiskey Harbor	Lake Huron	MI	Embayment-Open	44.00	82.72	3	C
Wigwam Bay	Lake Huron	MI	Tributary delta	44.04	83.71	335	CD
Wildfowl Bay	Lake Huron	MI	Sandspit embayment	43.78	83.44	165	AB-D
Wildfowl Islands	Lake Huron	MI	Embayment-Protected	43.86	83.44	1415	AB

Marsh*	Aquatic System	State	Site Type	Location		Size ^b (ha)	Rank ^c
				Latitude	Longitude		
Erie/St. Clair Lakeplain Marsh							
Clinton R.	Lake St. Clair	MI	Tributary delta	42.58	82.85	105	B-D
St. Clair R. Delta	St. Clair R.	MI	Connecting channel delta	42.58	82.50	3240	A-D
Erie Bay	Lake Erie	MI	Sandspit embayment	41.81	83.40	223	C-D
Otter Creek	Lake Erie	MI	Open lacustrine estuary	41.89	83.33	16	D
Pt. Mouillee	Lake Erie	MI	Tributary delta	41.96	83.23	465	B-D
Swan Creek	Lake Erie	MI	Open lacustrine estuary	41.92	83.29	45	C-D
Huron River	Lake Erie	OH	Barred lacustrine estuary	41.44	82.55	120	C
Old Woman Creek	Lake Erie	OH	Barred lacustrine estuary	41.41	82.51	160	C
Sheldon Marsh	Lake Erie	OH	Barrier-beach lagoon	41.48	82.60	200	C-D
Thompson Harbor	Lake Erie	PA	Sandspit swale	42.22	80.09	50	C
Presque Isle	Lake Erie	PA	Sandspit swale	42.19	80.14	260	A-C
Lake Ontario Lagoon Marsh							
Black Creek	Lake Ontario	NY	Barrier-beach lagoon	43.50	76.92	200	AB
Deer Creek	Lake Ontario	NY	Barrier-beach lagoon	43.82	76.35	500	A
Dexter Marsh	Lake Ontario	NY	Tributary delta	44.13	76.36	800	C
East Bay	Lake Ontario	NY	Barrier-beach lagoon	43.47	77.03	500	B
Lakeview Marsh	Lake Ontario	NY	Barrier-beach lagoon	43.93	76.39	1360	AB
Pt. Peninsula	Lake Ontario	NY	Barrier-beach lagoon	44.20	76.48	120	C
Sterling Creek	Lake Ontario	NY	Barrier-beach lagoon	43.50	76.83	360	C
St. Lawrence Estuaries							
Barnett Marsh	St. Lawrence R.	NY	Open lacustrine estuary	44.51	76.31	80	B
Chippewa Creek	St. Lawrence R.	NY	Open lacust. estuary & Delta	44.61	76.10	275	B
Cranberry Creek	St. Lawrence R.	NY	Open lacustrine estuary	44.56	76.17	175	B-C
Crooked Creek	St. Lawrence R.	NY	Open lacustrine estuary	44.66	76.07	340	AB
Delaney Bay	St. Lawrence R.	NY	Open lacustrine estuary	44.47	76.38	85	B-C
Flynn Bay	St. Lawrence R.	NY	Open lacustrine estuary	44.46	76.42	95	B

Table 2 (cont.)
Classification and Ranking of Great Lakes Coastal Wetlands

^a Sites marked with * contain transects classed both as Lake Superior Poor Fen and as Northern Great Lakes Marsh; see discussion in text.

Sites marked with ** are associated with the Rich Fen Group, and have calciphitic vegetation in at least one zone.

^b Size estimates are based on several different sources, including areas from existing detailed reports (Geis and Key 1977; Herdendorf et al. 1981a-1981f; Albert et al. 1987, 1988, 1989). For wetlands where no area computations exist in the literature, areas were computed by MNFI staff.

^c Ranking format:

The format A-C, A-D indicates that marsh habitat ranges from A quality to C or D quality in different portions of the wetland.

The format AB, AC is employed where the various factors used to assess quality differ, suggesting the need for an intermediate rank. For example, a large marsh in an intact landscape, but with minor amounts of exotic species is given a rank of AB, rather than a rank of A, which would have been appropriate if there were no exotics.

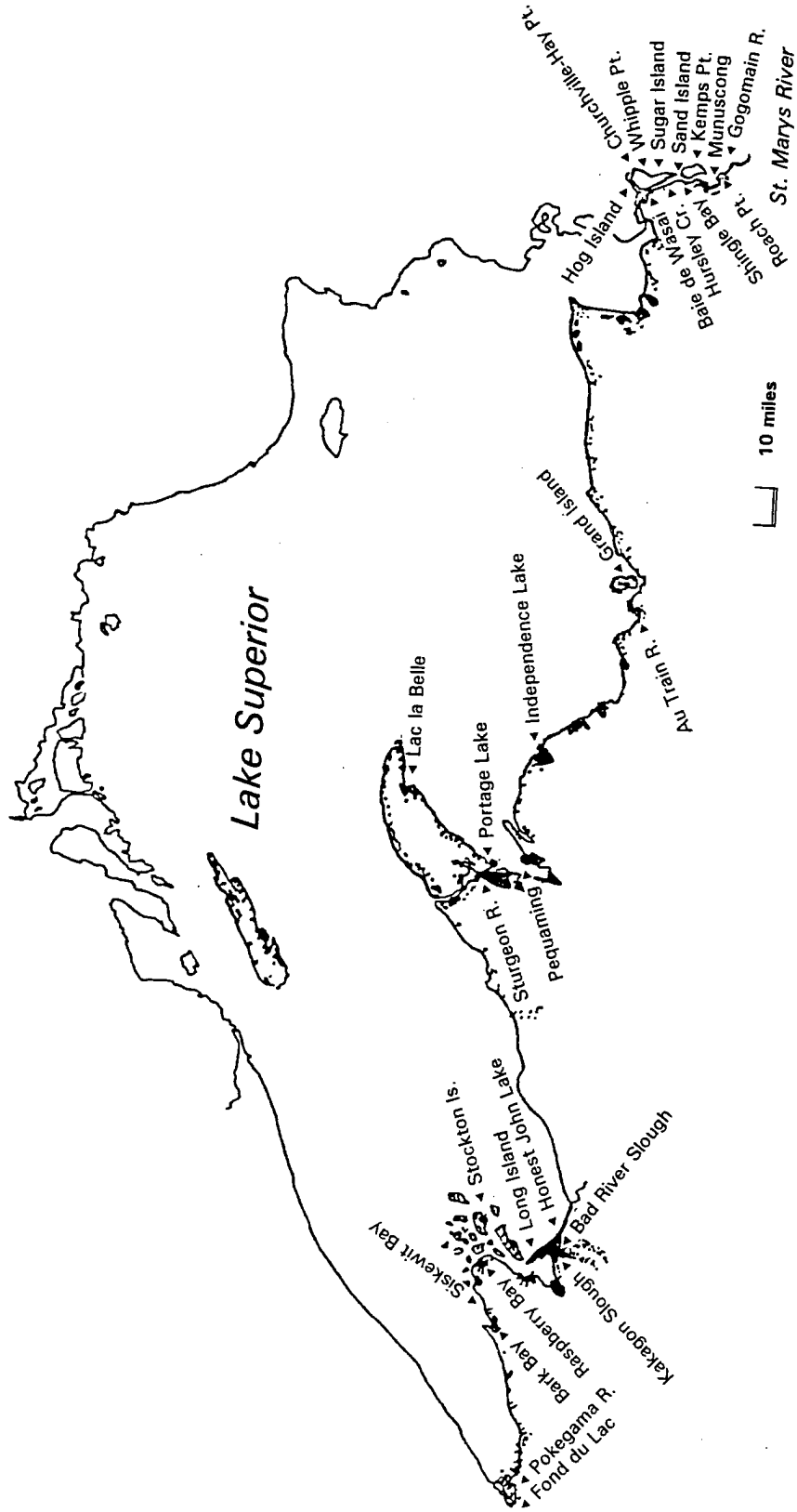


Figure 2. Identification and location of Lake Superior and St. Marys River coastal wetlands included in vegetation analysis. Base map showing wetland locations from Herdendorf et al. (1981a); not all wetlands mapped by Herdendorf et al. are directly influenced by Lake Superior water levels.

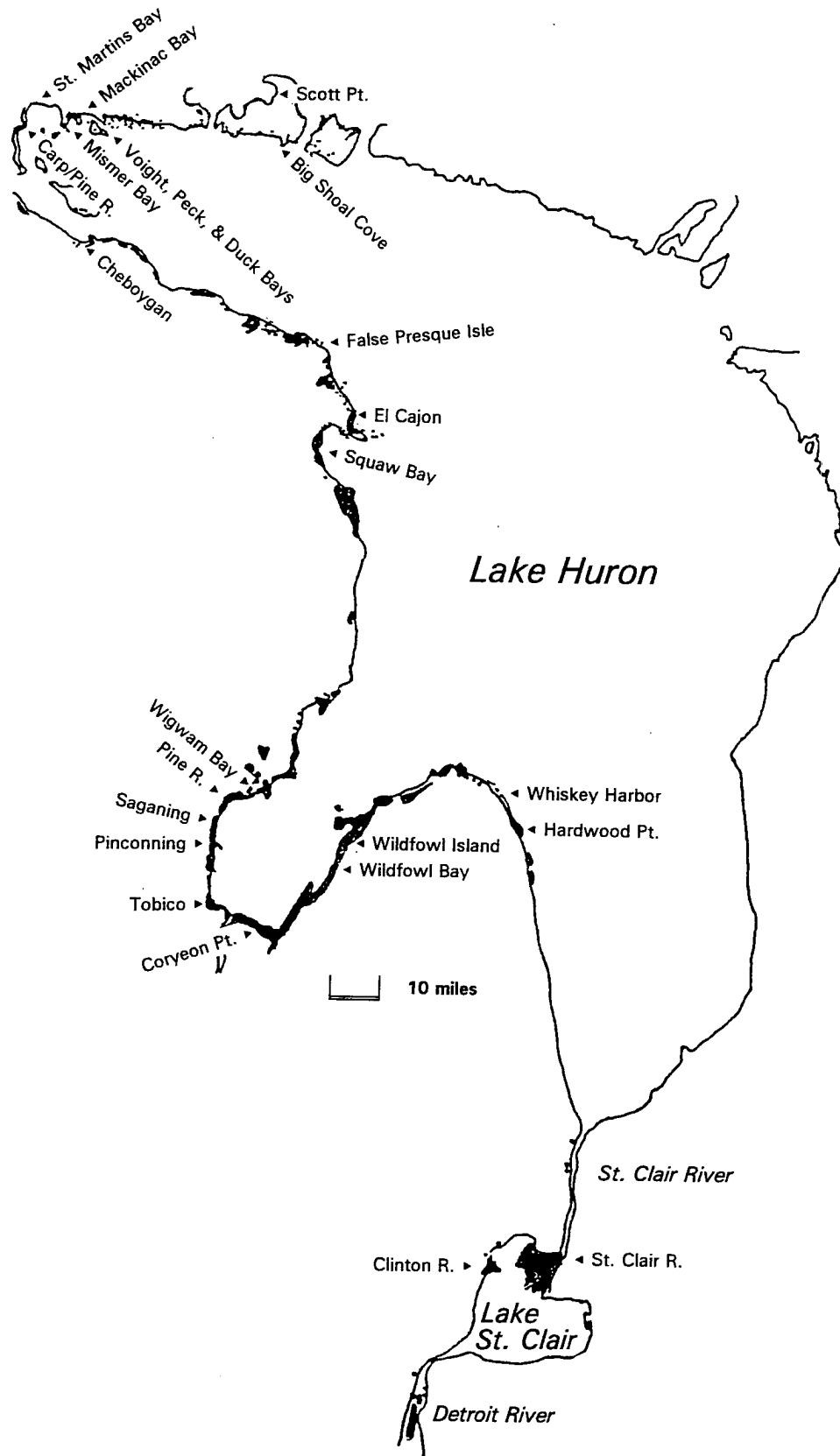


Figure 3. Identification and location of coastal wetlands from Lake Huron, St. Clair River, Lake St. Clair, and Detroit River included in vegetation analysis. Base map showing wetland locations from Herdendorf et al. (1981a).

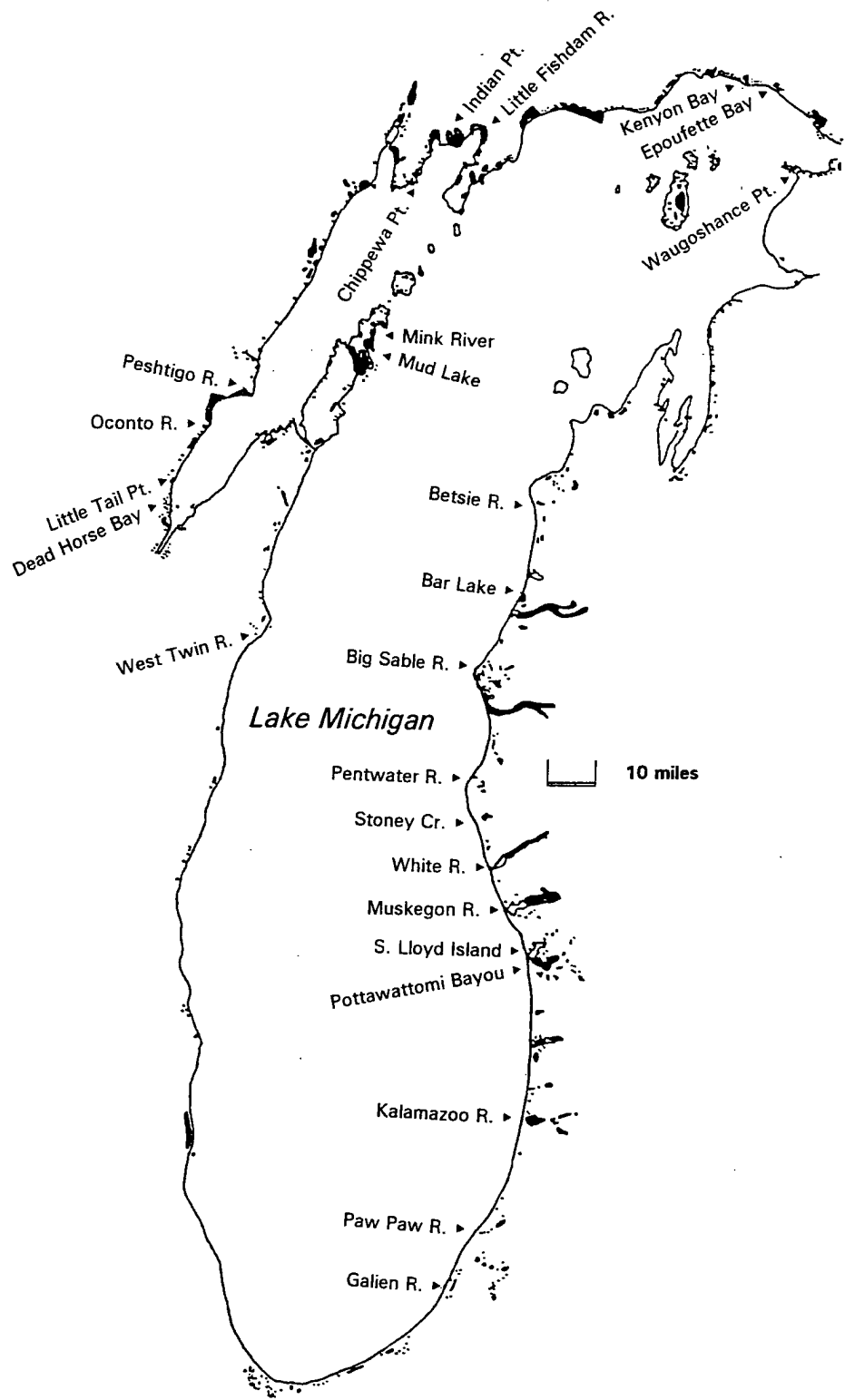


Figure 4. Identification and location of Lake Michigan coastal wetlands included in vegetation analysis. Base map showing wetland locations from Herdendorf et al. (1981a).

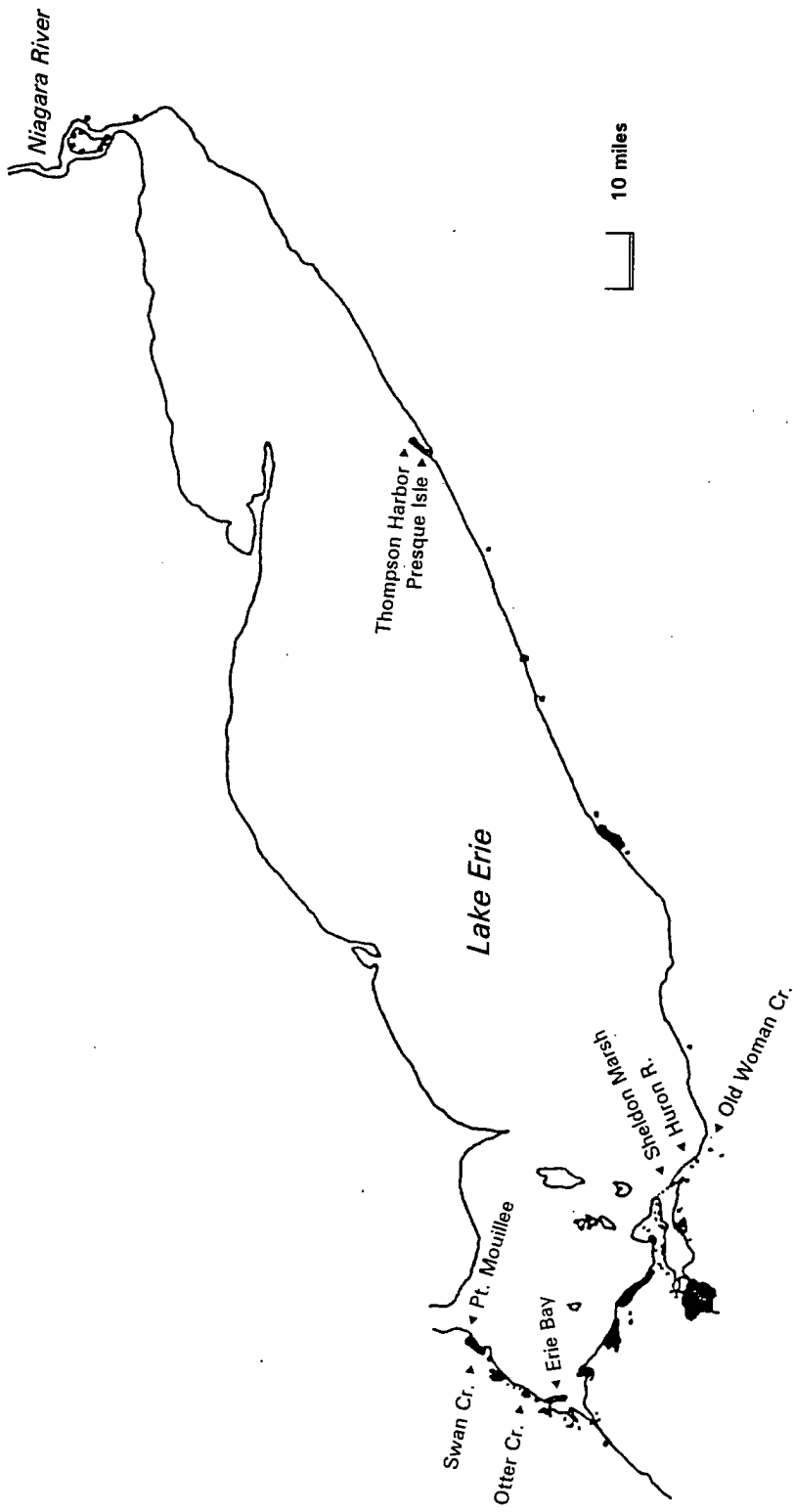


Figure 5. Identification and location of Lake Erie coastal wetlands included in vegetation analysis. Base map showing wetland locations from Herdendorf et al. (1981a).

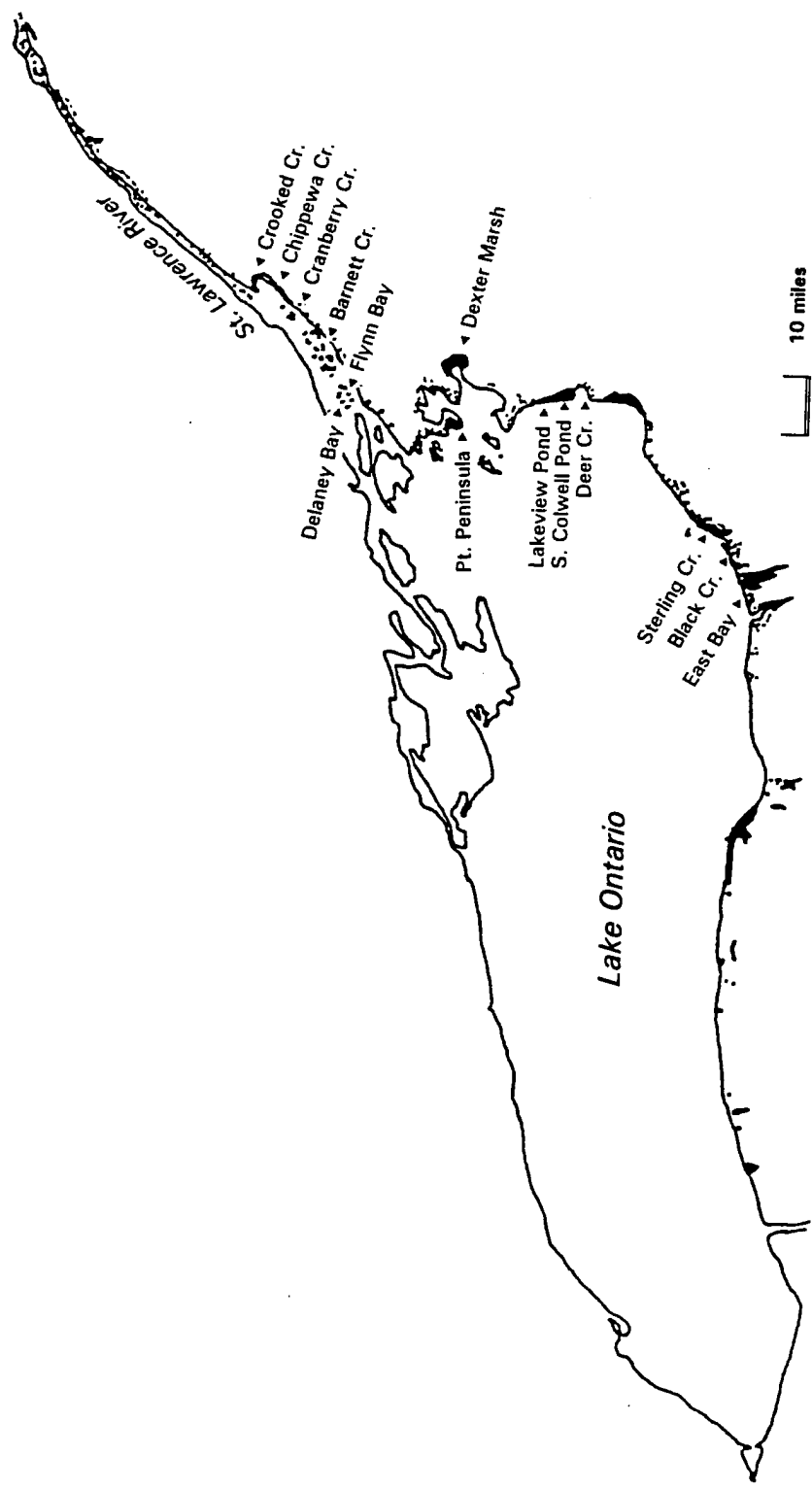


Figure 6. Identification and location of Lake Ontario and St. Lawrence River coastal wetlands included in vegetation analysis. Base map showing wetland locations from Herdendorf et al. (1981a).

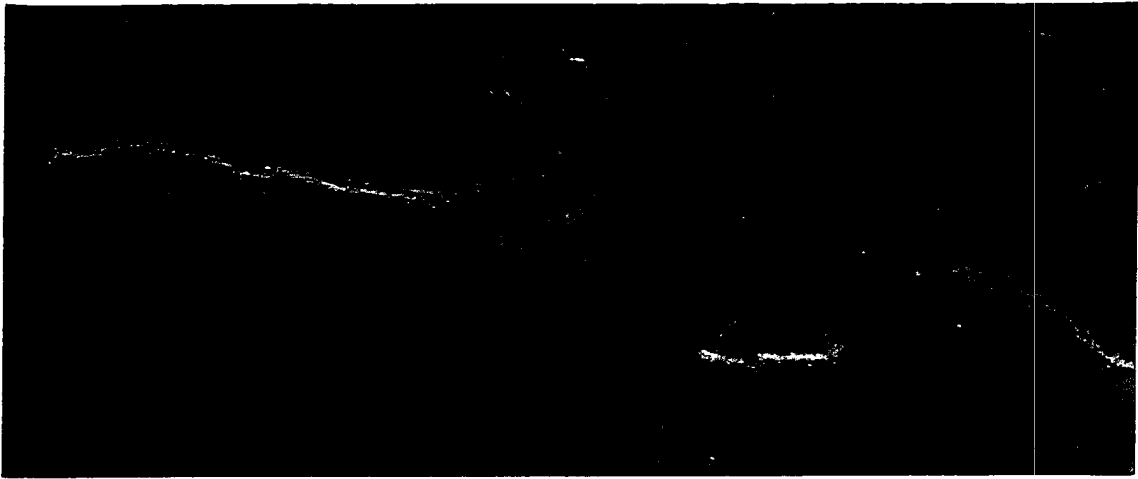
Plates

Plate 1. Wetland Site Types of the Great Lakes Shoreline

Plate 1a. Open embayment at Search Bay, northern Lake Huron. Curving sections of shoreline open to the lake typically provide minimal protection for coastal wetland development. Wetlands may establish in areas where shallow water depth and gently sloping bottom topography reduce wave height and energy, or in areas where nearshore bars and small sand spits block the waves, as at Search Bay. Even in more protected portions of the embayment, shifting sandy sediments can limit emergent wetlands to a narrow fringe; in contrast, fine-textured (clayey) substrates are ideal for aquatic macrophyte establishment and persistence, resulting in a continuous ring of emergent marsh. (Photo by Ted Cline, 1996).

Plate 1b. Open embayment at Voight Bay, Marquette Island, northern Lake Huron. Oriented toward the south, this bay is exposed to wave energies that develop across the full length of Lake Huron. Exposure to storm waves limits the development of emergent marsh and submergent marsh vegetation. Here, the rhizomes of hardstem bulrush attest to a narrow zone of emergent marsh that was destroyed by high water levels (1985-1986); recovery of this marsh has been very slow. A fringe of herbaceous vegetation rims the marshy shoreline. (Photo by Ted Cline, 1996).

Plate 1c. Protected embayment at Duck Bay, Marquette Island, northern Lake Huron. Indentations or embayments cut into resistant materials of the upland shoreline provide protection from wind and wave energy; tributary streams may flow into the basin, and organic and mineral sediments derived from adjacent uplands may accumulate, allowing development of diverse wetlands. Glacial deposition and subsequent modification of till created the protected embayments along the complex shoreline of the Les Cheneaux Islands, which are drumlinized ground-moraine features. (Photo by Ted Cline, 1996).

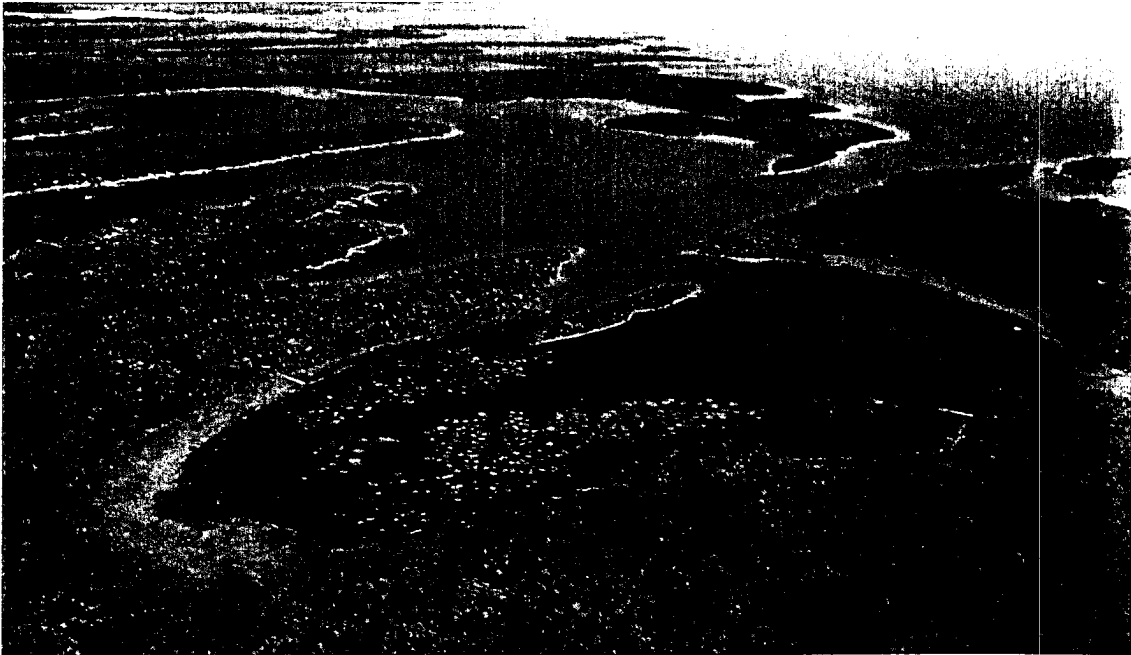


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Plate 1

b



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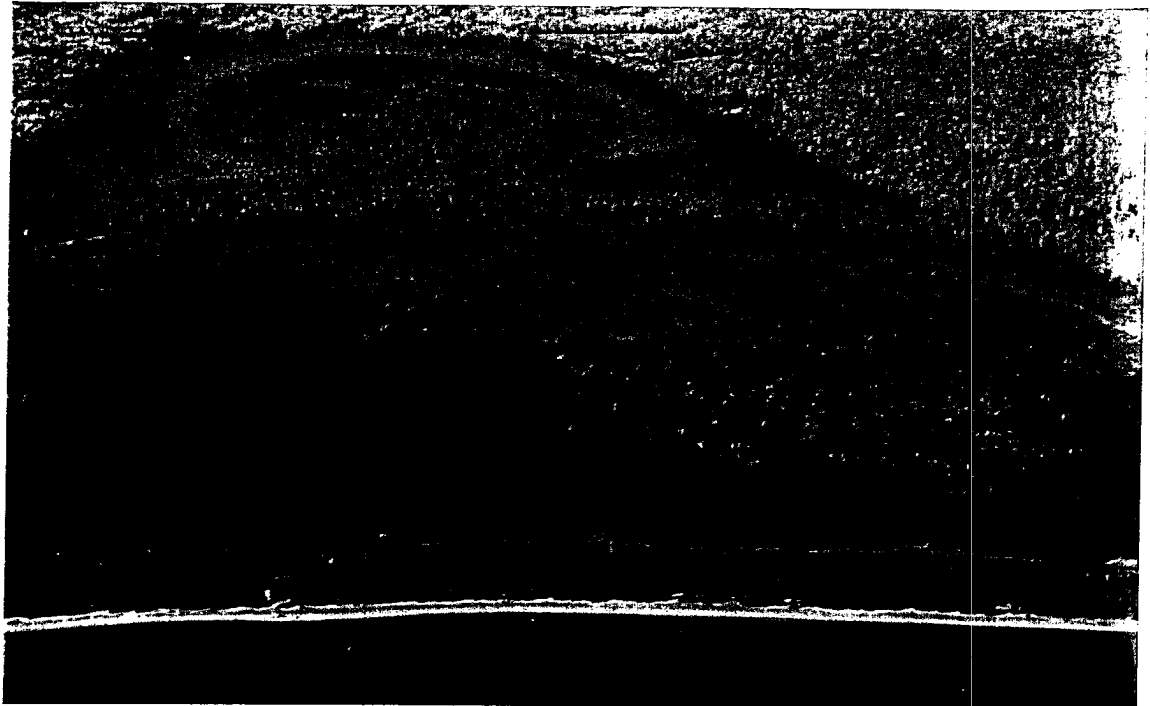
Plate 2. Wetland Site Types Created by Sand-transport Features

Barrier-beach lagoons are formed when nearshore currents deposit a sand or gravel barrier bar across the mouth of an embayment. The resulting shallow pond or lagoon is sheltered from the lake's wave energy; sediments accumulate in the lagoon basin and vegetation can become rooted. Although water levels in the lagoon may be augmented by tributary streams and groundwater seepage, coastal lagoon wetlands are also partially controlled by the Great Lakes, through permanent or intermittent connecting channels, wave overwash, or cross-bar seepage.

Plate 2a. Barrier-beach lagoon at Big Bay, Madeline Island, Apostle Islands, WI. Barrier beach lagoons are frequently bounded by steep, irregular topography in areas down-current from major sand-producing features where deep embayments trap sands moved by longshore currents. The irregular coastline along the till bluffs of the Bayfield Peninsula and Apostle Islands features numerous well-developed lagoons. Here, the two beaches reflect different lake levels and periods of barrier formation. (Photo by Eric Epstein, 1996).

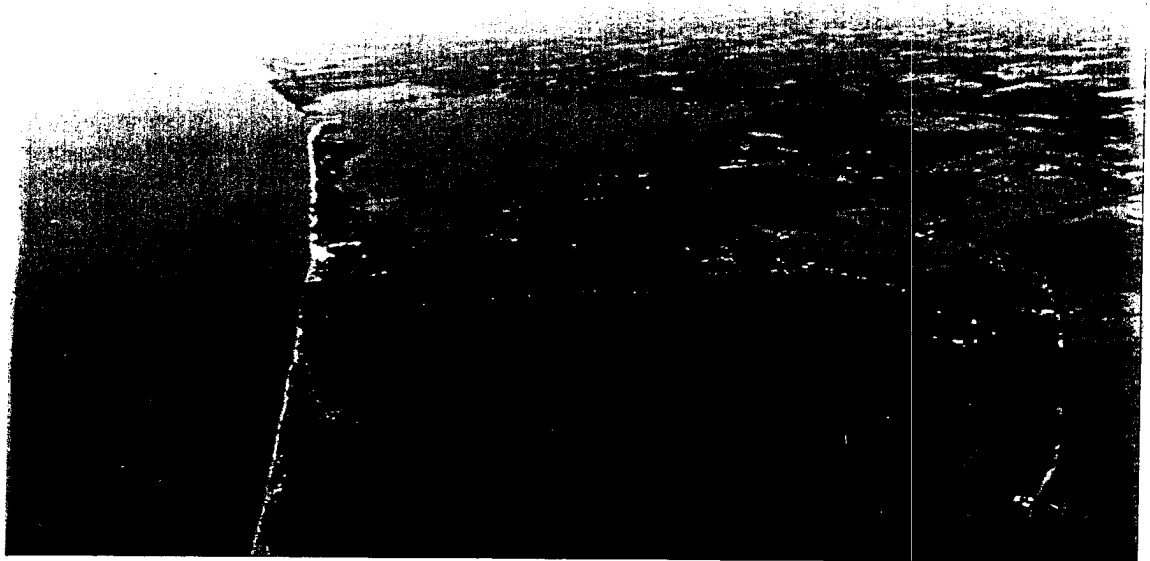
Plate 2b. Barrier-beach lagoon at Rainbow Shores/Sandy Pond, NY. Along the eastern end of Lake Ontario, predominant wind and water currents have accumulated sands eroded from glacial moraines to the west, creating a nearly continuous stretch of lagoons and wetlands between the barrier and the irregular moraine upland to the east. (Photo by John Griebisch 1990).

Plate 2c. Barrier-beach lagoon at Lakeview Pond Wildlife Management Area, Jefferson Co., NY. The barrier beach reduces wind and wave energies, allowing for the accumulation of fine sediments and the development of submergent and emergent vegetation communities behind the protective barrier. (Photo by D. Klein 1994).

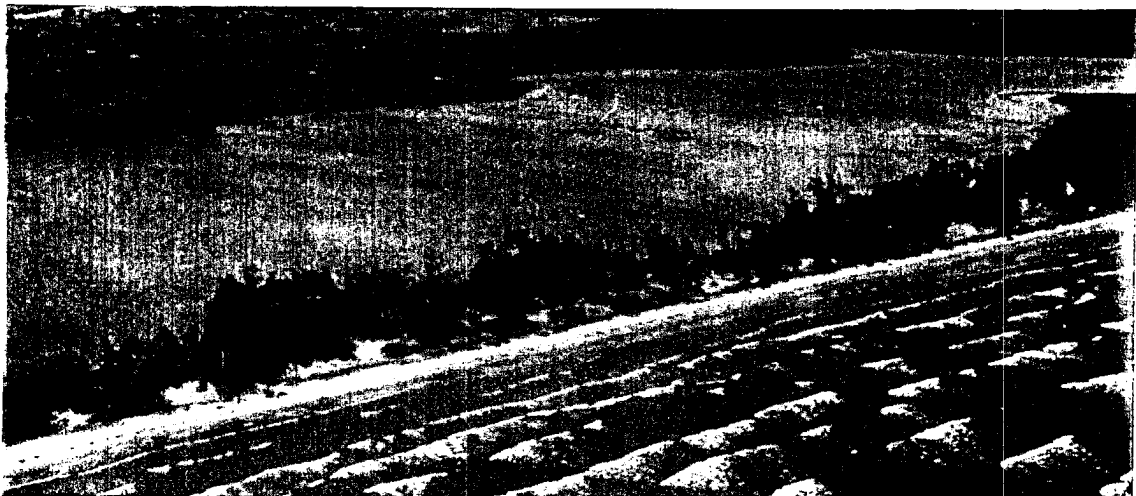


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Plate 2



b



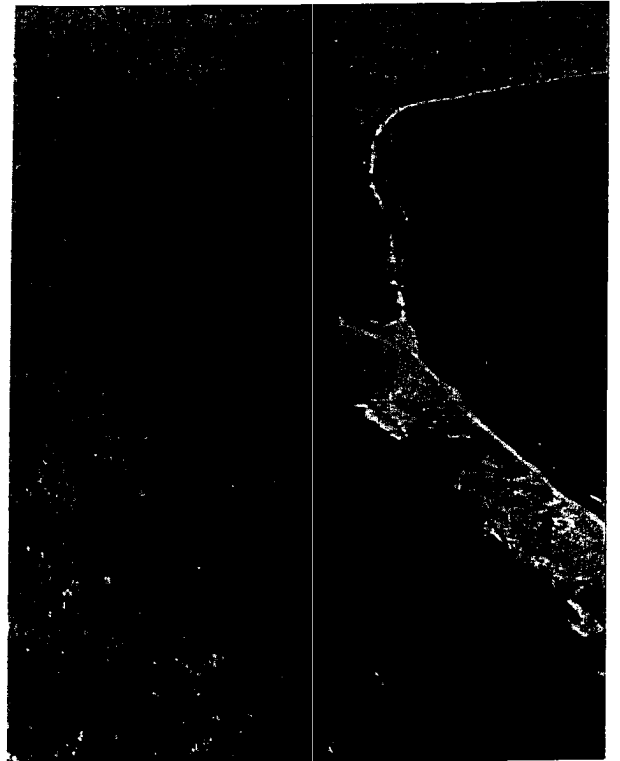
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Plate 3. Wetland Site Types Created by Sand-transport Features (cont.)

Plate 3a. Sand-spit embayment at Little Tail Point, Green Bay, WI. Formed by longshore transport, the sand spit creates and protects a narrow, shallow embayment on its landward side. On their lakeward side, such spits are exposed to wave activity and overwash; on their landward side, however, the spits generally provide good protection from wind and waves, allowing organic and fine mineral sediment accumulation and wetland development in the sheltered embayments. Large, recurved and compound sand spits may also enclose swales or lagoons which offer protected habitat for emergent vegetation. (Color infra-red photography, U.S. Army Corps of Engineers).

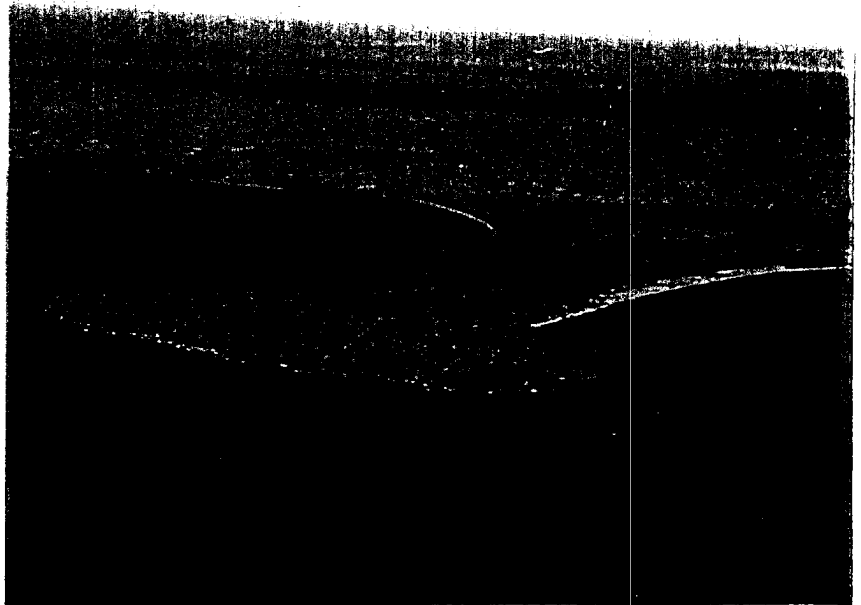
Plate 3b. Dune and swale complex at Stockton Island, Ashland County, Apostle Islands, WI. Alternating upland and wetland features formed as receding Great Lakes deposited a series of low sandy dunes or beach ridges (0.5 - 4 m high). From the air, these ridges appear as a series of arcs, generally parallel to the present shoreline. The flow of surface and ground water through these complexes can foster wetland development in the swales between beach ridges; water levels in lakeside swales are directly tied to Great Lakes water level fluctuations, while those further inland are not. Swales adjacent to the lake may contain open water and/or herbaceous wetlands; swales further inland, above the level of Great Lakes influence, more often support swamp forest or shrub swamp, although open water and herbaceous wetlands also occur. (Photo by Eric Epstein, 1996).

Plate 3c. Tombolo at Stockton Island, Ashland County, Apostle Islands, WI. Tombolos are islands connected to the mainland by current-deposited sands, which frequently form a series of parallel beach ridges. The bars or ridges may enclose a series of shallow interdunal swales, or larger lagoons within which thick organic soils and a dense growth of aquatic vegetation develop. The embayment created on the leeward side of the tombolo may receive sufficient protection from wave action that a fringe of emergent and submergent vegetation persists. (Photo by Eric Epstein, 1996).



b

Plate 3



C

Plate 4. Wetland Site Types of Riverine and Estuarine Systems

Deltas form when stream sediments are deposited and accumulate at the mouth of a river creating multiple shallow channels, low islands, and abandoned meanders that can allow for extensive wetland development. Wetland habitats within the delta range from the generally sandy or gravel substrates and swift current of the main channel, to the more protected secondary channels, where the slow to non-existent current permits thick accumulations of organics. Delta formation is best developed in areas of low gradient flow, where nearshore currents are relatively weak and thus do not rapidly remove deposited material.

Plate 4a. Delta of the Sturgeon River in Portage Lake, Upper Peninsula, MI. The Sturgeon River drops its sediment load as it enters Portage Lake, creating a well-developed delta. Several old meanders and oxbow ponds are clearly visible within the delta. (1978 color infra-red photography, Michigan Department of Natural Resources).

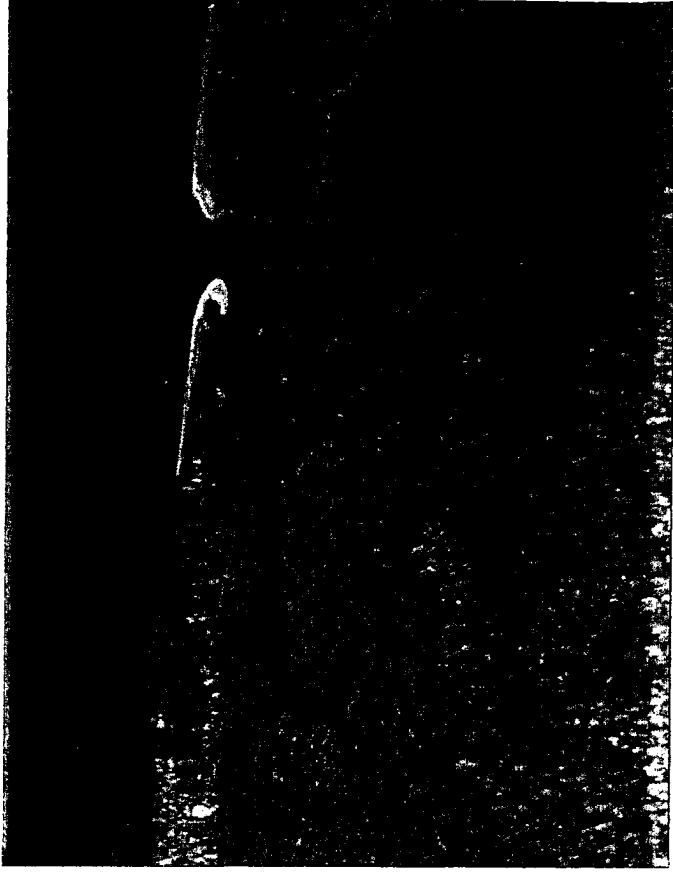
Lacustrine or freshwater estuaries, formed where some tributary rivers enter the lakes, represent a zone of transition from stream to lake within which water level, sedimentation, erosion, and biological processes are controlled by fluctuations in lake level. Most Great Lakes estuaries were formed as buried river mouths, when stream channels cut during an earlier time were drowned or buried by the subsequent rise in the Great Lakes to present water levels. Fairly steep upland slopes help shield the estuary, while reduced water velocities lead to deep accumulations of organics; the result is a protected, fertile (but topographically circumscribed) wetland. Longshore transport and infilling may modify the submerged river mouth, leading to distinct estuarine forms with different wetland characteristics.

Plate 4b. Open estuary at Sand River, Bayfield County, WI. Estuaries that are open to the lake typically display a branching inlet pattern that clearly reveals their origin as a drowned river mouth. Sand bars have formed at the mouth of this estuary, but do not appear to seriously impede water flow. (Photo by Eric Epstein, 1996).

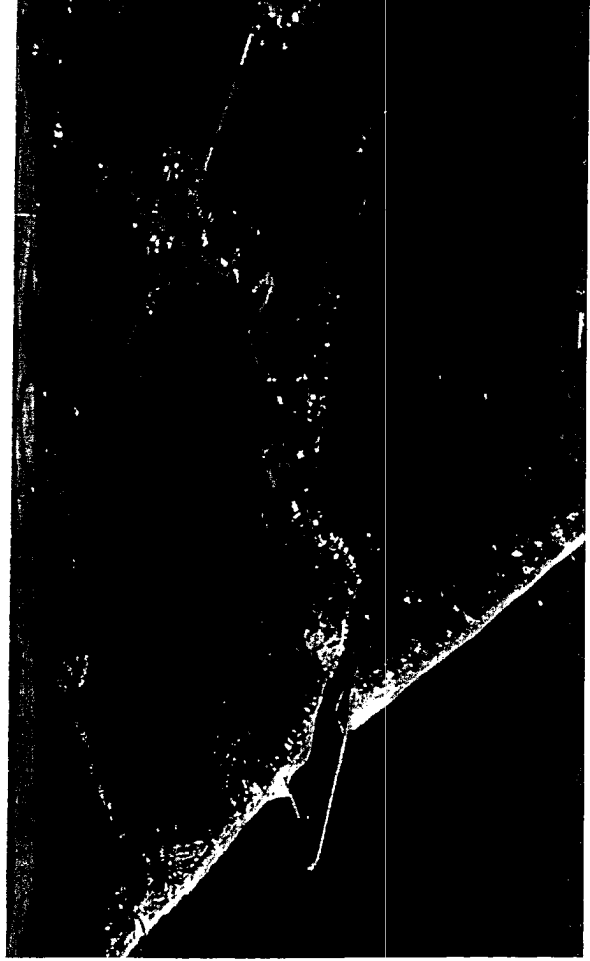
Plate 4c. Barred estuary at Salmon River, NY. Longshore transport has nearly barred this estuary by depositing a barrier dune across its mouth, slowing river discharge into Lake Ontario and forcing the river to meander broadly. The opening at the river mouth is now maintained by jetties. (Photo by John Griebisch 1990).



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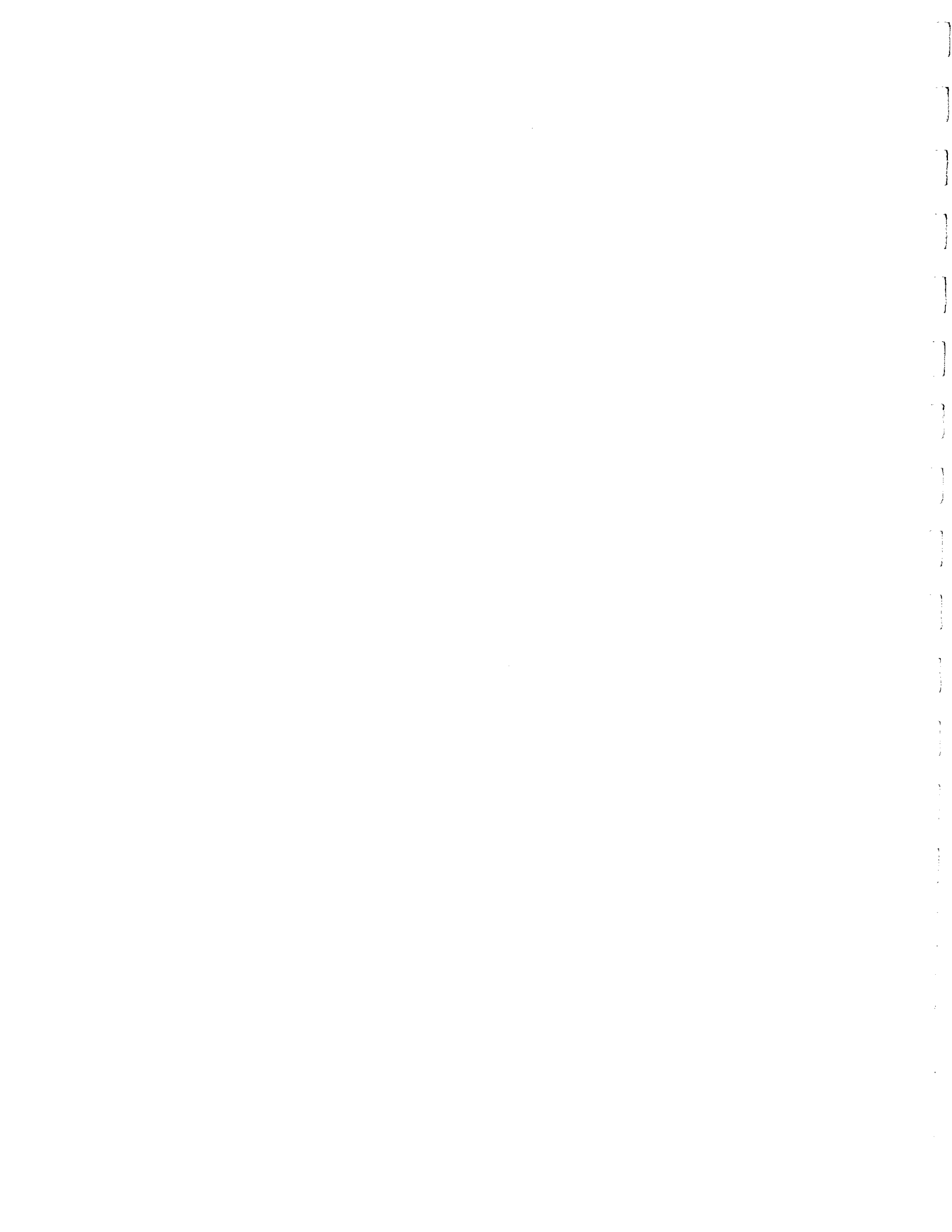


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c

Plate 4



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