Coastal Wetlands of Three Canadian Great Lakes: Inventory, Current Conservation Initiatives, and Patterns of Variation

P. G. R. Smith

Ontario Ministry of Natural Resources, 820 Yonge Street, R.R. 2, Aurora, Ont. L4G 3G8, Canada

V. Glooschenko

Ontario Ministry of Natural Resources, Toronto, Ont. M7A 1W3, Canada

and D. A. Hagen

Ontario Ministry of Natural Resources, Toronto, Ont. M7A 1W3, Canada

Smith, P. G. R., V. Glooschenko, and D. A. Hagen. 1991. Coastal wetlands of three Canadian Great Lakes: inventory, current conservation initiatives, and patterns of variation. Can. J. Fish. Aquat. Sci. 48: 1581–1594.

The decline of wetlands, including those in the Great Lakes coastal zone, prompted the Government of Ontario to initiate steps towards a wetland management policy in 1981. Wetland inventory and evaluation in southern Ontario began in 1983. To date, 1982 wetlands have been evaluated totalling 390 000 ha. These include 160 coastal wetlands, 64 of these on Lake Ontario and the remainder on the other Great Lakes and connecting channels. Current wetland conservation initiatives are outlined including the Wetlands Planning Policy Statement and Conservation Lands Act. Although the values of Ontario's coastal wetland areas are increasingly being recognized, there has been no comprehensive study to show patterns in coastal wetland ecology. Aided by analysis of variance, ordination, and cluster analysis, we show patterns of variation in wetland and site types, soils, dissolved solids, vegetation complexity, and rare flora and fauna which differ between wetlands along Lakes Ontario, Huron, Erie, St. Clair, and connecting channels. Wetlands of Lake Huron reflect a more northern species composition, less organic soil, and more swamp and fen habitat. Along Lakes Erie, Ontario, and St. Clair the predominant marshes have smaller swamp components, organic soils, and considerable dissolved solids.

L'assèchement des terres marécageuses, y compris celles de la zone côtière des Grands Lacs, a incité le gouvernement de l'Ontario à prendre des mesures en vue de l'établissement d'une politique de gestion des terres marécageuses en 1981. L'inventaire et l'évaluation des terres marécageuses du sud de l'Ontario a commencé en 1983. Jusqu'à maintenant, 1 982 terres marécageuses totalisant 390 000 ha ont été évaluées. Elles comprennent 160 terres marécageuses côtières : 64 bordent le lac Ontario et le reste, les autres Grands Lacs et les chenaux de navigation. Les grandes lignes de initiatives courantes pour la protection des terres marécageuses sont présentées, y compris la Déclaration de principes sur la planification de la gestion des terres marécageuses et la Loi sur la protection des terres. Même si la valeur des terres marécageuses côtières de l'Ontario est de plus en plus reconnue, aucune étude détaillée visant à établir les régimes écologiques des terres marécageuses côtières n'a été réalisée. À l'aide d'analyses de la variance, de grappes et d'ordination, on établit des régimes de variation pour ce qui et des types de terres marécageuses et de sites, des sols, deds solides dissous, de la diversité des végétaux ainsi que des espèces rares de faune et de flore qui varient selon les terres marécageuses des lacs Ontario, Huron, Érié et Sainte-Clair et des chenaux de navigation. Les terres maréageuses du lac Huron sont peuplées d'espèces caractéristiques des zones boréales, contiennent moins de sol humifère, mais englobent plus de marécages et de tourbières minérotrophes. Dans le cas des lacs Érié, Ontario et Sainte-Clair, les principaux marais englobent moins de marécages, contiennent moins de sols humifères, mais plus de solides dissous.

Received February 6, 1989
Accepted October 26, 1990
(JA038)

Reçu le 6 février 1989
Accepté le 26 octobre 1990

Wetland loss and degradation, particularly along the Great Lakes, has been of much concern to planners, resource managers, and the general public in both Canada and the United States (Francis et al. 1979; Herdendorf et al. 1986; Herdendorf 1987). Yet many coastal wetlands have not received sufficient protection to maintain their essential ecological functions for the future (Smith 1987).

Wetland loss on the Canadian side has been documented by a number of studies. Reid (1981) and Bardecki (1981) have commented on various aspects of wetland loss. Snell (1982, 1987) has estimated that over 1.4 million ha (61%) of southern Ontario's original wetlands have been converted since settlement times. McCullough (1981) described the loss of waterfowl habitat on Lakes Ontario and St. Clair. Change in habitat loss in the wetland area of western Lake Ontario was noted by Whillans (1982), and Lemay and Mulamoottil (1984) documented changing land uses in Lake Ontario waterfront marshes.

This paper seeks first to provide an overview of Ontario government initiatives on wetlands, particularly Great Lakes' coastal wetlands. In addition, the paper summarizes ecological knowledge of coastal wetlands on the Canadian side of the lakes based on recent inventories undertaken as part of the government's wetland program. Graphical and statistical methods are used in these analyses.

Coastal Wetland Values

A review of the values of coastal wetlands was provided by Herdendorf et al. (1986). Some of the greatest values for coastal wetlands lie in their habitat potential for migratory birds and waterfowl. For Lake Ontario, Dennis and Chandler (1974), Dennis et al. (1984), and Crowder and Bristow (1988) have documented the utility of wetlands with regard to waterfowl. Their value for fish habitat is also well recognized. Stephenson (1988, 1989) has recently documented fish use of coastal marshes for various aspects of reproduction throughout the year (spawning, nursery). In addition, Herdendorf (1987) has noted that these coastal wetlands are important because of the cover they provide for juvenile and forage fish. Approximately 43 species of fish are or once were associated with the coastal marshes of western Lake Erie. Often as much as 90% of the standing fish crop in wetlands consists of forage species.

Wetland Inventory and Evaluation

The decline of wetland resources in Ontario prompted the Government of Ontario to initiate steps towards a wetlands management policy in 1981. The first major components of this initiative centred on a cooperative federal–provincial mapping inventory of the wetland resource and on development of an inventory and evaluation system. The mapping was completed by Environment Canada for all of southern Ontario (Snell 1987).

Development of a wetland inventory and evaluation system was initiated in 1981 by the Wildlife Branch of the Ontario Ministry of Natural Resources (OMNR) and Lands Directorate/ Canadian Wildlife Service of Environment Canada. This document drew from many sources, including a wetland evaluation model proposed by the Federation of Ontario Naturalists (Reid et al. (1980) as discussed by Patterson (1984). From 1981 to 1983, preliminary versions of the Ontario Wetland Evaluation System were tested and modified. Glooschenko (1983) has discussed the evolution of this evaluation system. The current version (Environment Canada and the OMNR 1984) has been in use for five complete field seasons.

The primary goal of wetland inventory and evaluation is to rank wetlands for the purposes of setting planning and management priorities. Such ranking is a planning tool that can be incorporated into government policy to facilitate informed land-use decisions.

Wetland inventory and evaluation includes field reconnaissance inventory of each wetland. This includes the identification and mapping of vegetation communities, summary of existing knowledge about rare species, and measurement of other variables such as exposure to wave action.

When complete, these field data are coupled with knowledge of local biologists and naturalists and translated into evaluation scores using formulae laid out in the wetland manual. These scores are then used to rank the wetlands into seven different classes, class 1 being the highest or most valuable and class 7 being the lowest ranked.

Both the inventory and evaluation deal with biological, social, hydrological, and special feature information. In the scoring scheme, each of these four components has a maximum score of 250 points. Each component is weighted equally in determining the final ranking of a wetland.

Ontario's provincial wetland guidelines give priority for protection to provincially significant wetlands (classes 1 and 2) as specified in OMNR's (1984) wetland guidelines and to those additional wetlands (classes 3–7) identified by municipalities as significant and addressed within their planning documents.

Inventory and Evaluation Results

A program of wetland inventory evaluation began in 1983 and to date, 1982 wetlands have been evaluated, totalling 390 000 ha. A large portion of southern Ontario's wetlands have now been evaluated and this includes 160 coastal wetlands and wetland complexes, 64 of these on Lake Ontario and the remainder on the other Great Lakes and connecting channels.

Although the values of Canadian coastal wetland areas are increasingly being recognized, there has been no comprehensive study to show ecological relationshps within the coastal wetlands. An earlier paper (Glooschenko 1985) compared some Great Lakes coastal wetlands with inland wetlands that were assessed by OMNR. The present paper describes patterns of variation in wetland and site types, soils, vegetation complexity, and rare and significant flora and fauna which differ significantly between wetlands in the different geographic areas. The features of 64 Lake Ontario coastal wetlands are treated in some detail, including characterization of their variation in relation to coastal geomorphology.

Conservation Initiatives

In the past several years, there have been a number of provincial initiatives to conserve and manage wetlands as well as one to provide coordinated management of the shorelines of the Great Lakes.

In December 1986, OMNR initiated a provincial shoreline management program. The goal of the program was to minimize danger to life and property damage from flooding, erosion, and other similar hazards along shorelines and to ensure that shoreline development adequately addresses flooding and erosion hazards through both public and private management and development alternatives (OMNR 1987). Guidelines distributed in 1987 identify the preservation, protection, emergency response, public information, environment, and monitoring components of Shoreline Management Plans.

Recent wetland policy and program initiatives include the release of a new Draft Wetlands Planning Policy Statement under the Planning Act and the announcement of the Conservation Lands Tax Reduction Program. Both are discussed below.

Wetlands Planning Policy Statement

The 1983 Planning Act states that the "protection of the natural environment" and "features of significant natural ... interest" are "matters of provincial interest."

The Planning Act is the primary piece of legislation governing municipal planning in Ontario. Under section three of the Act, the Province is able to articulate land use interests in the form of policy statements. These policy statements are released first in draft for public review and comment and then formally approved under the Planning Act. Once approved, all municipalities, provincial government ministries, agencies, boards, and commissions are required to have regard to the provisions of those policy statements.

The provincial government has had a long-standing commitment to the protection of wetlands, and in November 1988 it released a Draft Wetlands Planning Policy Statement for public review and comment. The proposed Wetlands Planning Policy Statement will not, by itself, ensure wetland protection. It is one element of a comprehensive wetland management program administered by OMNR.

The proposed Wetlands Planning Policy Statement contains policies to identify and protect provincially significant class 1 and 2 wetlands. Regional and local municipalities may apply the provisions of the policy statement for those wetlands within their planning jurisdiction which are deemed to be regional or local in significance.

The proposed policy statement applies province-wide, even though the evaluation system on which wetlands are classified applies only to those wetlands located south of the Precambrian Shield. OMNR has also initiated the development of an evaluation system for northern Ontario, but until this latter system is in place, wetland values in Ontario are defined in consultation with OMNR as those which (i) provide habitats required for the maintenance of healthy fish or wildlife populations of importance to achieving provincial management objectives, and/or (ii) have an essential hydrological role in the watershed where they exist, and/or (iii) have a significant social or economic benefit.

The draft policy is based on the following principles:

(1) Wetlands are essential natural resources and the Province is committed to their protection.

(2) There will continue to be demands on wetlands for conversion to other land uses. Some of these demands may have to be accommodated, and for this reason the policy statement establishes criteria by which the need for locating land uses in and adjacent to wetlands can be fully evaluated.

(3) All planning authorities in Ontario will share in the responsibility for protection of wetlands.

The draft policy states that all municipalities, planning boards, and resource management agencies should identify and protect provincially significant class 1 and 2 wetlands within their jurisdictions in the context of local, regional, and provincial land use planning objectives. Class 3–7 wetlands may also be identified in planning documents and protected in a manner deemed appropriate by municipal authorities.

New land uses permitted on, or adjacent to, a provincially significant wetland should be compatible with the wetland so that the wetland values are maintained or improved, as defined by the evaluation system. In northern Ontario, above the Precambrian Shield where the evaluation system does not apply, changes in wetland values will be assessed by OMNR on a site-specific basis.

Wetlands are also to be placed in a restrictive zoning category which permits only natural features and land uses compatible with wetland maintenance. In consideration of any such proposals, the criteria for land-use compatibility should take into account that total evaluation score and classification of each wetland be maintained or improved.

If land-use change is justified in accordance with the above, the development should be carried out in a manner to minimize its negative impact on the affected wetland.

To aid in implementation, OMNR will (i) inform landowners and the general public on the value of wetlands and provide information on wetland management, as well as maps and other technical information, (ii) make a presentation or provide technical expertise to the Ontario Municipal Board or other appeal body where a matter related to this planning policy may be at issue, and (iii) issue the associated Implementation Guidelines for the Wetlands Policy Planning Statement and jointly administer the policy statement with the Ontario Ministry of Municipal Affairs (OMMA).

The mandate of OMMA includes the administration of the Planning Act. It is responsible for the review and/or approval of various municipal land-use planning documents and for ensuring that municipalities and planning authorities have had regard for the Wetlands Planning Policy Statement. OMNR and OMMA are jointly responsible for the administration of the Wetlands Planning Policy Statement.

Conservation Lands Tax Reduction Program

The Conservation Lands Tax Reduction Program provides up to 100% tax rebate to landowners of class 1–3 wetlands as well as certain other heritage lands. The tax reduction program, provided under the Conservation Lands Act, is an incentive for private landowners to maintain in a natural state those lands which contribute to Ontario's conservation and heritage objectives. To be eligible, landowners must agree to maintain the land for the long term and not to conduct activities which would have a negative impact on its values.

Evaluation and Inventory of Great Lakes Coastal Wetlands

Methods of Analysis

In the following section of the paper, we analyze the data collected on each of the 160 coastal wetlands evaluated by OMNR (Fig. 1). The intent is to (1) describe the diversity of wetland types along the Great Lakes and their connecting channels, (2) investigate factors that contribute to patterns of variation, and (3) develop empirical classifications of the types of coastal wetlands.

Methods of analysis used include analysis of variance, both parametric and nonparametric, cross-tabulation, ordination, and cluster analysis. Where numeric variables conformed to the assumptions of a normal distribution and homogeneity of variances, parametric analyses of variance were performed. In some cases, logarithmic and arcsine transformations were used to normalize distributions and stabilize variances (Steele and Torrie 1980). In other cases, the Kruskal–Wallis nonparametric test was used. An ordination using principal components analysis revealed the primary gradients of wetland variation. Centred, standardized principal components analysis with varimax rotation was the ordination technique used (Pielou 1984). Other ordination techniques, such as detrended correspondence analysis and multidimensional scaling, are also popular in such ecological analyses (Gauch 1982; Pielou 1984). Cluster analysis indicated the general categories of wetlands based on their physical structure and vegetation composition. Ward's minimum variance clustering method was employed (Gauch 1982; Pielou 1984).

Variables used in the analyses include numeric variables measuring the wetlands' site type (lacustrine, riverine, etc.), wetland type (marsh, swamp, etc.), soil type, nutrient status, and vegetation complexity (see Environment Canada and OMNR (1984) for definitions and detailed descriptions of these variables). A number of categorical variables classifying the wetlands' vegetation interspersion, open-water configuration, and exposure to wave action were also analyzed. In multivariate

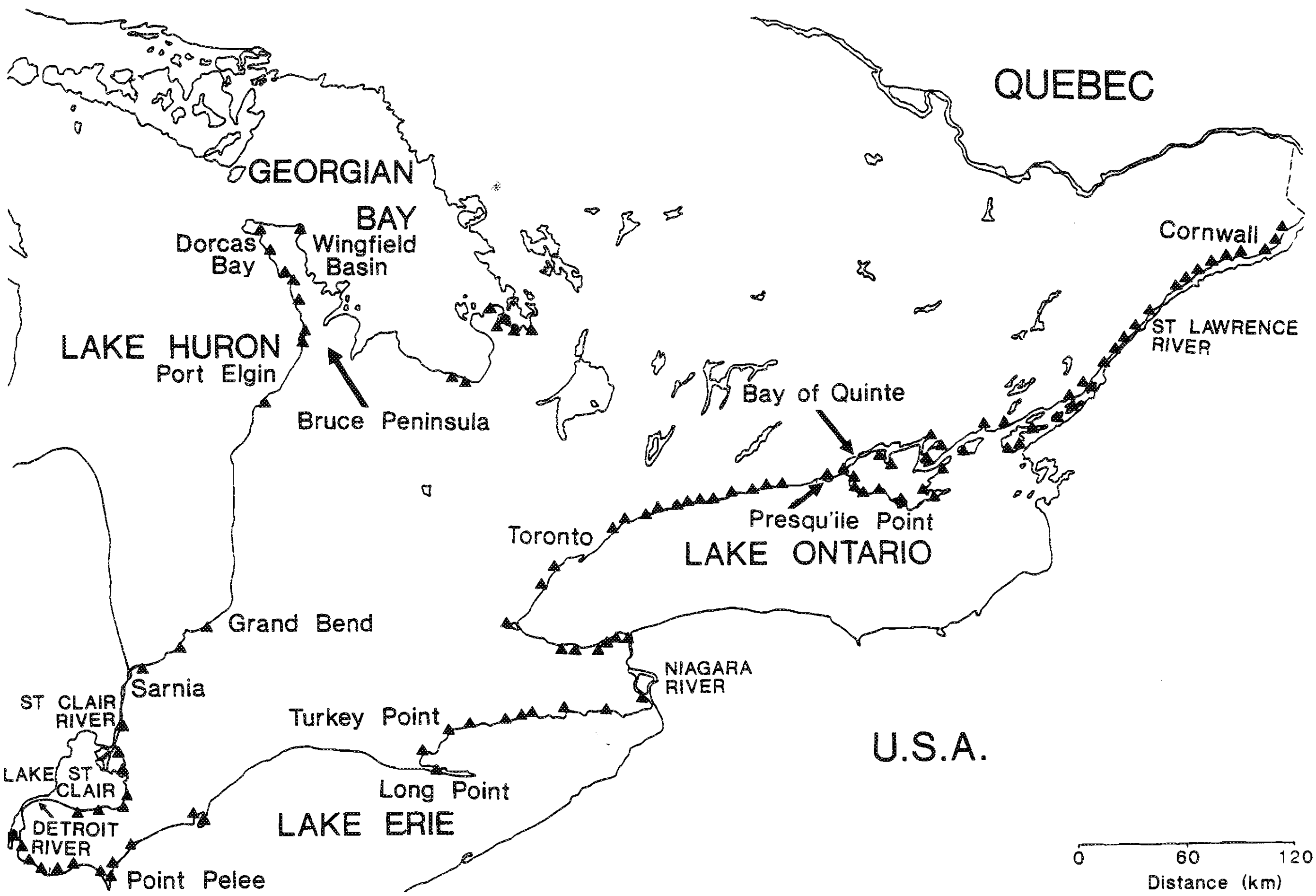

FIG. 1. Location of coastal wetlands (triangles) of the Great Lakes and connecting channels evaluated by OMNR. Note that one triangle may represent more than one wetland or wetland complex.

analyses, these categorical variables were included as "dummy" variables (i.e. either 0 or 1 for each category; see Draper and Smith 1984). Similarly, the dominant plant taxa of each wetland's vegetation communities were recorded as present or absent (i.e. 1 or 0).

The species composition of wetland vegetation communities is not emphasized in the wetland evaluation system. Rather the structural or physiognomic composition is the major focus. Thus, only dominant species can be used in the analysis presented here. Because OMNR wetland assessments are based on reconnaissance inventory rather than detailed inventory, a number of species were lumped into genera or family groups (e.g. Poaceae, Cyperaceae, *Acer*). A sample of 80 wetlands was used in multivariate analyses, as these have consistent and comparable data on dominant species composition.

Results and Discussion

The inventories and evaluations of wetlands undertaken by OMNR include 160 wetlands along the Great Lakes and their connecting channels with a total area of almost 40 000 ha (Fig. 1 and 2). Virtually all of these are south of the Precambrian Shield and lie along Lakes Ontario, Erie, St. Clair, and Huron, Georgian Bay, and the St. Lawrence, Niagara, Detroit, and St. Clair rivers. Seven wetlands along the northwestern coastline of Lake Superior were evaluated by the Lakehead Region Conservation Authority but were not included in analyses because of differences in methods.

Most wetlands along the Great Lakes and connecting channels score highly and are ranked in the higher classes of 1–3 (Fig. 2). They score particularly highly in the special features and social components of the evaluation system. Hydrological scores are lower than inland wetlands (Collins and Maltby 1984; Glooschenko 1985).

General Characteristics of the Wetlands of Each Lake and Connecting Channel

St. Lawrence River

Along the St. Lawrence River, 3500 ha of wetland habitat at 27 sites have been assessed by OMNR (Fig. 1 and 2). These primarily are wetlands along river shores and at the mouths of smaller rivers which enter the St. Lawrence. Marsh is the predominant wetland type. A variety of physiographic environments surround the St. Lawrence River between Lake Ontario and the Quebec border. The Frontenac Axis, a southern extension of the Precambrian Shield, with its low, rounded hills, forms the Thousand Islands. Farther downstream, limestone plain, till plain, and riverine deposits are characteristic (Chapman and Putnam 1984). Environment Canada (1985) described

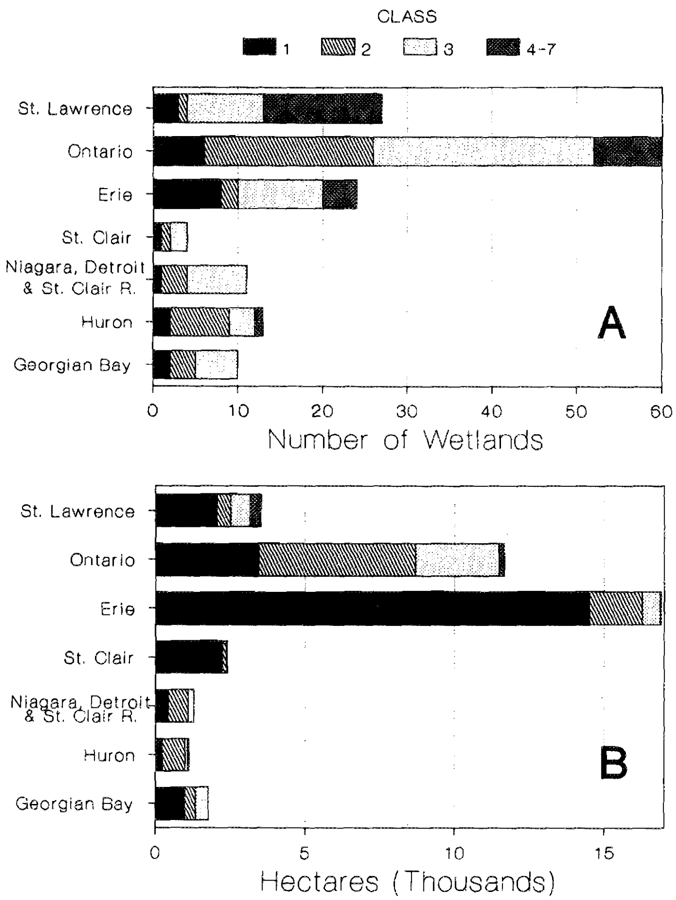

FIG. 2. (A) Numbers and (B) hectares of coastal wetlands evaluated along the Great Lakes and connecting channels. Numbers and hectarage in each class are shown.

St. Lawrence River wetlands between Cornwall and the Gulf of St. Lawrence. Species composition appeared quite similar to the lower St. Lawrence wetlands described here, except that *Typha* appeared to be a less dominant genus upstream. That study typified the wetlands as occurring in areas of weak current, shallow bays and on deposits of clay and gravel. Auclair et al. (1976) studied the interrelationships between environmental parameters and plant community productivity and structure in emergent *Scirpus–Equisetum* stands in the Lake St. Francis portion of the river. Tidal freshwater and brackish water marshes with dominants such as *Spartina* characterize St. Lawrence River wetlands in Quebec nearer the Gulf of St. Lawrence (Lacoursiere 1969).

Lake Ontario

Lake Ontario's 64 wetlands totalling almost 12 000 ha are scattered along the shores in river mouths and embayments and behind bars and barriers (Fig. 1, 2, and 3). These wetlands dot the entire length of the lake, but the largest portion of the wetland area is concentrated east of Presqu'ile Provincial Park.

The coastal geomorphology of Lake Ontario coast has determined the form of the wetlands. East of Presqu'ile is a limestone plain from which glaciers stripped most of the overburden (Chapman and Putnam 1984). Along the shores of the Bay of Quinte, particularly on the southern shore, deeper clay sediments are present. The large Sawguin Creek and Big Island Marshes lie here. Crowder et al. (1986) described in some detail the wetlands and fauna of the Bay of Quinte. The southern and eastern sides of Prince Edward County have irregular coastlines where deep valleys dissect the shoreline and form long deep bays that are often closed by baymouth bars (Chapman and Putnam 1984; Whitcomb et al. 1973). Such sites possess large wetlands such as those at Weller's Bay, West Lake, Pleasant Bay, and Big Sandy Bay.

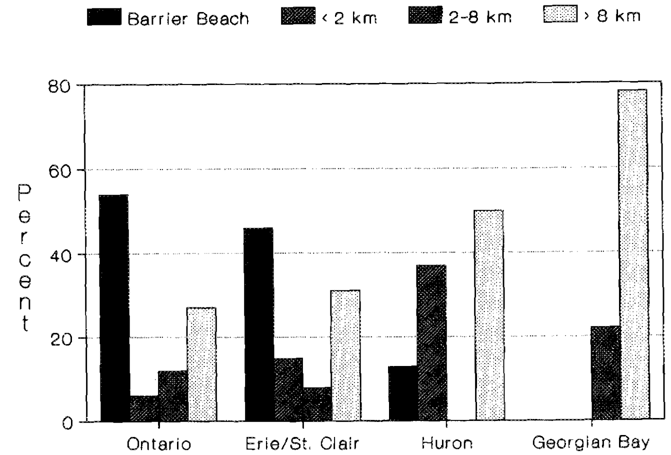

FIG. 3. Presence of barrier beaches and fetch distances for Great Lakes coastal wetlands. Percentages are significantly different between the water bodies (chi-square, $P < 0.05$).

The shores of the western end of Lake Ontario are composed of a variety of glacial tills and lacustrine deposits overlying several different types of bedrock. The surficial material dates from previous postglacial lakes, particularly Lake Iroquois. In a number of areas, these deposits are actively eroding and form bluffs, most notably at the Scarborough Bluffs. In yet other areas, river valleys, cut during prehistoric times of lower water levels, are "drowned" by present lake levels. Many wetlands form in these locations, notably in the Niagara Peninsula. These sites include Jordan Harbour and Martindale Pond as well as the mouths of 15, 16, and 17 Mile creeks. T. Whillans, R. Smardon, and W. Busch (unpubl. data) noted that the waterfront wetlands of western Lake Ontario generally have high macrophyte productivity and interspersion of vegetation types.

Lake Ontario's wetlands are, on average 80% marsh and 20% swamp. Bog habitat occurs at Nut Island Duck Club Marsh on Amherst Island and Big Sandy Bay on Wolfe Island; a fenlike "panne" habitat occurs at Presqu'ile Provincial Park. Fifty-five percent of Lake Ontario's total wetlands lie behind barrier beaches (Fig. 3). Twenty-nine percent of the wetland (area) is in a riverine location, 27% is on protected bays, another 25% is in river mouth locations, 17% is exposed to the lake proper, and less than 2% is palustrine (Fig. 4).

Thirty-three different provincially significant bird species, as designated by the wetland evaluation system (see Environment Canada and Ontario Ministry of Natural Resources 1984), occur in Lake Ontario's coastal wetlands. The six most frequent species are shown in Fig. 5. Some of these species demonstrate affinities for the Great Lakes shorelines as discussed earlier (also see Glooschenko et al. 1988a). Others like the northern harrier have no particular affinity for coastal wetlands.

Nineteen different plant species in Lake Ontario's coastal wetlands are considered provincially rare by Argus et al. (1982–88). Two species are found primarily in the eastern end of Lake Ontario. *Alisma gramineum* occurs, and indeed is sometimes

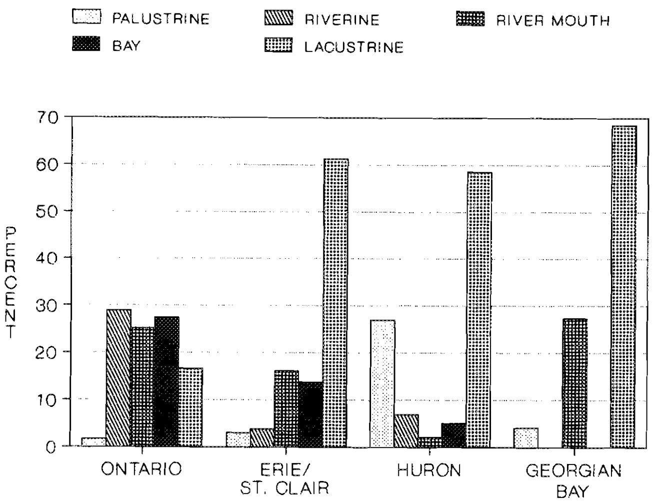

FIG. 4. Percentage of wetland area in the different site types for the Great Lakes.

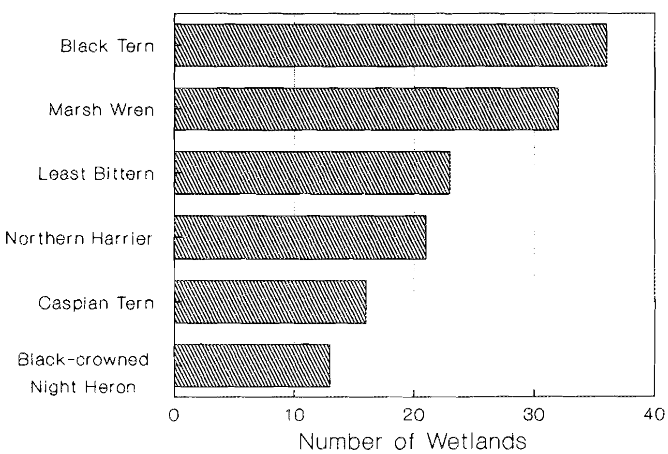

FIG. 5. Number of Lake Ontario wetlands in which the six most frequent provincially significant birds species occur: black tern (*Chlidonias niger*), marsh wren (*Cistothorus palustris*), least bittern (*Oxobrychus exilis*), northern harrier (*Circus cyaneus*), Caspian tern (*Sterna caspia*), and black-crowned night heron (*Nycticorax nycticorax*).

very abundant, in nine wetlands east of Presqu'ile Provincial Park, particularly those on Wolfe Island. *Alisma gramineum* is widely distributed in western North America, but in the eastern part of the continent is restricted to the St. Lawrence Valley and eastern Lake Ontario. In four wetlands in Prince Edward County and on Wolfe Island, *Peltandra virginica* is present. *Peltandra virginica* is also widely distributed in the eastern and southern United States but is found only at a few widely scattered localities in Ontario.

Lake Erie

The 28 Lake Erie coastal wetlands and wetland complexes occupy almost 17 000 ha (Fig. 1 and 2), two thirds of which are contained in the Long Point wetland complex which includes Long Point proper, Big Creek, Turkey Point, and wetlands lining Long Point Bay. Other large wetlands exist west of Long Point. Some of these are the swamps and marshes of Rondeau Bay, major wetlands at the mouths of Cedar and Big creeks in Essex County, and, of course, Point Pelee (Herdendorf 1987). Smaller wetlands are scattered along the shorelines east of Long Point primarily at rivermouths. Large, lake-influenced wetlands occur up the mouth of the Grand River near the eastern end of Lake Erie. Clay and sand plains border the Lake Erie shoreline.

Niagara, Detroit, and St. Clair rivers

Seven wetlands totalling over 1200 ha occur along the Detroit River, particularly near its mouth (Herdendorf 1987), where thousands of waterfowl stage during migration periods (Dennis et al. 1984). Wetlands assessed on the connecting channels include one on the Niagara River and three on the St. Clair River (Fig. 1 and 2).

Lake St. Clair

Lake St. Clair is well-known for its extensive and important wetlands (McCullough 1981, 1985; Herdendorf et al. 1986). Four wetlands totalling over 2400 ha have been evaluated by OMNR (Fig. 1). These lie along the eastern shore, at the mouth of the Thames River, and at two sites along the south shore. The particularly large (over 10 000 ha) Walpole Island marshes have not yet been evaluated using OMNR wetland methods, as they lie outside provincial jurisdiction. Walpole and other islands form the massive delta of the St. Clair River, a classic example of a bird's foot digitate delta (Bird 1984).

Lake Huron

Lake Huron has 13 wetlands consisting of 1300 ha (Fig. 1 and 2). The coastline has few natural barriers, estuaries, or drowned river valleys and portions are highly developed for recreational use. Considerable diversity in coast type exists. From Sarnia to Point Edward, sandy beaches prevail with some lagoon wetlands (Chapman and Putnam 1984). Kettle Point, a bedrock shelf, juts out into the lake and provides a sheltered site for another wetland. The meanders of the Ausable River transect the dune system at Pinery and Ipperwash; between the dunes lie the large Port Franks interdunal forested swamps and wet meadows. From Grand Bend to Port Elgin, a shorecliff of 15–30 m in height defines the shoreline and precludes wetland development. On the Bruce Peninsula, where the shore is primarily dolostone bedrock, a more complex coastline has developed. Wetlands are more numerous and include shoreline fens, such as that at Dorcas Bay, generally uncommon elsewhere on the Great Lakes shores. A number of these wetlands were also analyzed in detail by Charlton (1986; also Charlton and Hilts 1989) in his study of fens, marshes, and bogs in the Bruce Peninsula. A number of wetlands along the coast of Manitoulin Island were discussed by Smith (1987). The attributes of some coastal marshes in Bruce County were described by Fahselt and Maun (1980).

Georgian Bay (Lake Huron)

Only the portion of Georgian Bay southwest of the Precambrian Shield has been surveyed by OMNR for wetlands. A total of 1829 ha in 10 wetlands have been evaluated to date (Fig. 1 and 2). The rugged shoreline of the eastern side of the Bruce Peninsula prevents the development of extensive wetlands. One exception is Wingfield Basin, a small, sheltered cove at the base of the Niagara Escarpment at Cabot Head. The long, often sandy shoreline of Nottawasaga Bay also lacks wetlands, except in interdunal areas, the few harbours, and rivermouths. Southeastern Georgian Bay, while rocky, includes some sheltered embayments where a number of shoreline marshes have developed. Noteworthy amongst these are the marshes of Matchedash Bay.

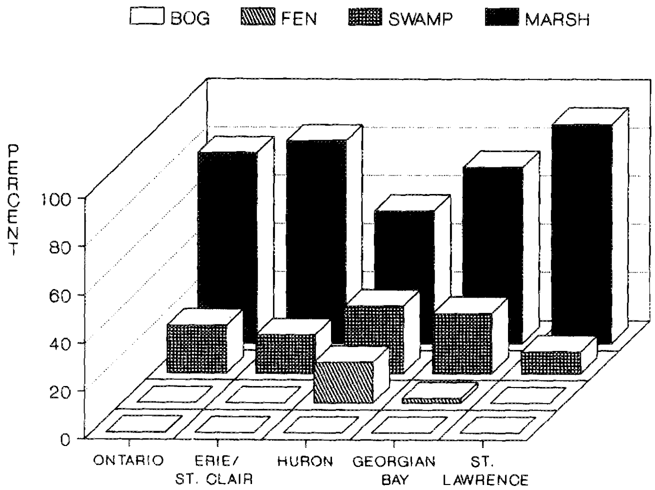

FIG. 6. Wetland types for coastal wetlands on the Great Lakes and St. Lawrence River. Percentage of marsh, swamp, and fen is significantly different between lakes (for statistic and P values, see Table 1).

Patterns of Variation

Wetland type

Overall, the dominant wetland type in southern Ontario is forest swamp (Glooschenko et al. 1987). In contrast, Ontario's Great Lakes coastal wetlands, like those on the American side, are predominantly marsh (Fig. 6; also see Herdendorf et al. 1981; Glooschenko 1985; Herdendorf et al. 1986; Herdendorf 1987). The classic pattern described by many authors is a band of submerged plants farthest lakeward, emergents somewhat closer to shore, and a zone of shrub and forest swamp in the backshore area. This gradient of water depth is one of the major gradients influencing the structure and composition of shoreline wetlands (Hutchinson 1975; Day et al. 1988). The well-known fluctuations of water levels in the Great Lakes contribute to this preponderance of marsh and to the diversity of vegetation by contributing to natural disturbance (Keddy and Reznicek 1986). Disturbance gradients are another key determinant of wetland vegetation (Day et al. 1988).

Predominance of marsh, however, is not uniform along the lakes. Lake Huron wetlands, particularly those along the western side of the Bruce Peninsula, have a higher percentage of fen and swamp habitat and less marsh (Fig. 6; Table 1). Most fen habitat develops in areas with calcareous bedrock such as the Bruce Peninsula (Reddoch 1982; Charlton 1986; Charlton and Hilts 1989). The percentage of wetlands on a protected bay, presence of a barrier beach, and fetch distance (Table 1; Fig. 3 and 4) are all measures of level of disturbance due to wave and storm action. Swamp habitat in Great Lakes wetlands is positively associated with wetland location on protected bays (F-test, $P < 0.05$).

Soil composition and productivity

Soil composition in wetlands varies significantly among the lakes (Table 1; Kruskal–Wallis test, $P < 0.01$; soil composition determined from the soil maps). The soils of the wetlands of Lakes Ontario, Erie, and St. Clair contain a significant percentage of organics (Fig. 7). Soils on Lake Huron consist of a lower percentage of organics. Georgian Bay wetlands are almost entirely underlain by mineral soils (Fig. 7; Table 1). This reflects a north–south productivity gradient as well as differences in substrate and physiographic location. The north–south productivity gradient is reflected in the significant difference in levels of total dissolved solids among the lakes (Table 1). Levels are lower in northern wetlands of Lake Huron, Georgian Bay, and the St. Lawrence River than in those of the more southern lakes.

Coastal geomorphology

Barrier beaches are prevalent on Lakes Erie and Ontario, particularly the latter (Fig. 3). The genesis of these landforms often dates to previous postglacial lakes that had higher water levels. Drowned river valleys, artifacts of previous postglacial lakes, also provide a sheltered environment in which organic soil can accumulate. These are notable features along Lake Ontario, especially in the Niagara region and along the northwest shore. Almost 28% of wetlands occur in the numerous sheltered bays along Lakes Erie and Ontario, particularly eastern Lake Ontario (Fig. 4). All these protected locations would promote the formation of organic soils because of little wave action.

In contrast, the wetlands of Lake Huron and especially Georgian Bay are primarily lacustrine wetlands (Fig. 4) exposed to some wave action and storm events. This higher disturbance precludes the development of organic soils. Similarly, the wetlands along the St. Lawrence River, which are also exposed to flows of greater velocity and energy, are primarily underlain by mineral soils (Fig. 7; also see Environment Canada 1985).

Vegetation complexity

The complexity of wetland vegetation varies among the lakes. The wetland evaluation system (Environment Canada and OMNR 1984) defines vegetation communities and requires that they be mapped. Communities are separated on the basis of number of vegetation forms present (similar to Raunkier life forms; Mueller-Dombois and Ellenberg 1974). The number of vegetation forms in communities differs significantly among the lakes (Table 1; all $P < 0.05$). Analysis of covariance was used to remove the effects of wetland area and number of wetlands in wetland complexes, as vegetation diversity is clearly related to these variables. In general, wetlands along Lake Huron and Georgian bay have more complex vegetation communities than those on Lakes Ontario, Erie, and St. Clair and the St. Lawrence River. The greater amount of swamp habitat and of palustrine site type (Table 1) on Lake Huron and Georgian Bay is related to this greater vegetational complexity. Different elevations and ranges in elevation contribute to this complexity.

Colonial waterbird habitat

The occurrence of colonial nesting waterbirds in coastal wetlands also differs among the lakes (Fig. 8). More wetlands on Lakes Ontario, Erie, and St. Clair support nesting waterbirds than those along Lake Huron and Georgian Bay (Fig. 8). Some noteworthy exceptions exist; for example, Nottawasaga Island near Collingwood supports a large colony of great blue herons (*Ardea herodias*), black-crowned night herons, and, recently, great egrets (*Casmerodius albus*) (also see Weseloh et al. 1986; Smith 1987). Many species reach their range limits in Ontario (Cadman et al. 1987) and are restricted to the lower lakes.

Waterfowl habitat

The critical importance of wetlands of the Great Lakes and St. Lawrence River for waterfowl has been documented by many studies (Dennis and Chandler 1974; Dennis et al. 1984; Ross 1984; Crowder and Bristow 1988). The wetland evaluation system defines various levels of significance for waterfowl

TABLE 1. General characteristics of coastal wetlands on the Great Lakes and St. Lawrence River.

	St. Lawrence River	Lake Ontario	Lakes Erie and St. Clair	Lake Huron	Georgian Bay	Statistically significant difference[a]
Number of wetlands	27	64	28	13	10	N/A
Area of wetlands (ha)	3511	11 555	19 306[b]	1274	1829	N/A
% marsh[c]	91.2	79.1	83.9	5.1	73.3	***[d]
% swamp[c]	8.8	20.3	16.1	27.8	24.6	*[d]
% fen[c]		0.2		16.7	2.1	****[d]
% bog[c]		0.1				N/A
% palustrine and isolated[e]	0.7	2.4	3.9	27.0	4.1	N/A
% riverine[e]	95.8	28.9	3.9	7.0		N/A
% rivermouth[e]	3.5	25.2	16.4	2.2	27.4	N/A
% lacustrine on bay[e]		27.5	13.8	5.2		N/A
% lacustrine[e]		16.6	61.3	58.6	68.5	N/A
% organic soil[b]	6.2	45.4	50.3	31.9	0.0	**[d]
% mineral soil[d]	89.6	53.7	49.7	68.1	100.0	**[d]
Mean total dissolved solids	220.3	339.3	297.5	202.3	195.0	**[d]
Number of vegetation communities	9.1	9.6	6.8	32.2	11.8	***[f]

[a]Statistical tests where appropriate; probability levels: *$0.05 > P > 0.01$; **$0.01 > P > 0.001$; ***$P < 0.001$.
[b]Walpole Island marshes account for at least another 10 000 ha.
[c]Mean value for all wetlands.
[d]Kruskal–Wallis test.
[e]Calculated based on total area in each type for all wetlands.
[f]Analysis of variance with covariates wetland area and number of wetlands in wetland complexes.

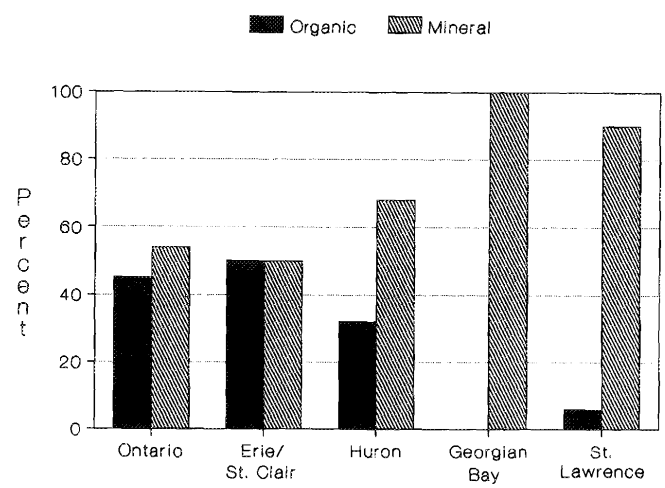

FIG. 7. Average percentage wetland area underlain by organic and mineral soils for the Great Lakes and St. Lawrence River. Percentage of organic and mineral soils is significantly different between lakes (for statistic and P values, see Table 1).

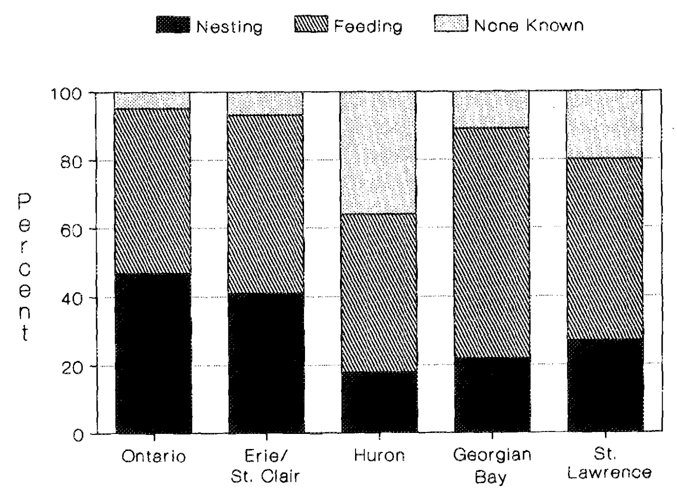

FIG. 8. Presence of habitat for colonial waterbirds in coastal wetlands along the Great Lakes and St. Lawrence River (significant differences, chi-square, $P < 0.01$).

presence and states how these may be determined. An assessment is given of whether the wetland is of national, provincial, regional, or local significance for waterfowl staging and of provincial, regional, local, or no significance for waterfowl production. Three coastal wetlands were assessed as nationally significant for waterfowl staging. Fourteen were considered provincially significant for staging and 6% for waterfowl production. Thirty-one were regionally significant for waterfowl staging and 10% for waterfowl production.

Fish habitat

The importance of Great Lakes coastal wetlands as fish habitat has never been assessed comprehensively. Goodyear et al. (1982) mapped and described known spawning and nursery habitat on both sides of the lakes. Smith (1987) integrated that study with several others to map the more significant fish habitat. More recently, Stephenson (1988, 1989) has shown that coastal wetland habitat is considerably more important for fish reproduction than previously noted.

As with waterfowl, the wetland evaluation system defines various levels of significance for fish spawning and rearing. The importance of spawning and rearing habitat in each wetland may be classified as regionally significant, present, unknown, or unclassifiable. Thirty coastal wetlands were assessed as of regional significance for fish spawning and rearing. However, these and other wetlands might have greater value for fisheries if spawning and nursery values were estimated. OMNR is currently in the process of revising the evaluation system, and fisheries values will receive increased recognition.

Rare and significant species

Rare species contribute to the rating of wetlands in Ontario and are of particular concern to wetland managers (for definition of rare species, see Environment Canada and OMNR 1984). The Great Lakes possess a number of plant and animal species and subspecies that are endemic to the lake waters and shores (Guire and Voss 1963; Campbell et al. 1981; Smith 1987). Some of the plants are considered rare in Ontario and Canada (Argus et al. 1982–88). Records of the occurrence of rare species in wetlands are often taken from secondary sources such as local naturalists, published studies, and other surveys of natural areas. Consequently the inventories of rare species are often incomplete and are frequently updated by OMNR staff as new information becomes available.

Endangered species

Ontario's Endangered Species Act designates 18 species as endangered. The bald eagle (*Haliaeetus leucocephalus alascanus*) occurs at 11 coastal wetlands, primarily along Lake Erie where additional birds are being released into the wild. Formerly the bald eagle was relatively frequent along the Lower Great Lakes shorelines (Brownell and Oldham 1983). The peregrine falcon (*Falco peregrinus anatum*) uses four wetlands during migratory periods.

Bird species

The most frequent of the rare bird species is the black tern which occurs at 68 coastal wetlands. The black tern is also considered threatened in Canada. The marsh wren is nearly as frequent, occurring at 64 wetlands. Forty-four wetlands support least bittern, rare in Canada, and black-crowned night heron. The Caspian tern is found at 32 wetlands, while the common tern (*Sterna hirundo*) frequents 25 coatal wetlands. Twenty-three wetlands harbour the pied-billed grebe (*Podilymbus podiceps*). A number of these species have been shown to occur more frequently in shoreline than in inland wetlands: black tern, marsh wren, Caspian tern, and black-crowned night heron (Glooschenko et al. 1988a). In Ontario, black-crowned night heron and Caspian tern nest primarily on the shores of the Great Lakes (Cadman et al. 1987; Blokpoel 1977; Blokpoel and McKeating 1978; Weseloh et al. 1986).

Reptiles and amphibians

The eastern fox snake (*Elaphe vulpina gloydi*), a subspecies endemic to the Great Lakes coasts, is the most frequently recorded rare reptile, occurring at 18 sites. At 11 wetlands the spotted turtle (*Clemmys guttata*) can be found, and at nine the eastern spiny softshell turtle (*Trionyx spiniferus spiniferus*) has been noted. Massasauga rattlesnakes (*Sistrurus catenatus*) frequent six of the coastal wetlands, primarily those on the Bruce Peninsula. Two wetlands support the Lake Erie water snake (*Nerodia sipedon insularum*), an endangered, endemic subspecies known only from the islands in the western end of Lake Erie (Oldham 1983; King 1986).

Fish species

Coastal wetlands harbour a number of rare fish species, many of which are on the northern edge of their ranges (Campbell et al. 1981; Campbell 1984, 1985; McAllister et al. 1985; Smith 1987). Spotted gar (*Lepisosteus oculatus*), silver chub (*Hybopsis storeriana*), pugnose shiner (*Notropis anogenus*), brindled madtom (*Noturus miurus*), and spotted sucker (*Minytrema melanops*) were recorded at wetlands along Lakes Erie and St. Clair. Undoubtedly, many other rare species frequent waterfront wetlands, and as Stephenson (1988) has shown, further field studies of coastal wetlands for fish habitat use are needed.

Plant species

A number of the endemic Great Lakes plant taxa are found in coastal wetlands. Most of these occur on Lake Huron and Georgian Bay. Many of the Great Lakes' endemic plants are distributed here as well as along Manitoulin Island, the northern portion of Lake Michigan, and extreme eastern Lake Superior (also see Guire and Voss 1963; Morton 1979; Keddy and Keddy 1984). The exceedingly rare Houghton's goldenrod (*Solidago houghtonii*) occurs at one Georgian Bay wetland (Morton 1979; Semple and Ringius 1983). Also along the Lake Huron coast of the Bruce Peninsula, Hill's thistle (*Cirsium hillii*) can be found at three wetland sites, while the dwarf lake iris (*Iris lacustris*) and stiff yellow flax (*Linum medium medium*) occur at one wetland each.

Many southern Carolinian plant taxa reach their range limits along the shores of Lake Erie. Swamp rose mallow (*Hibiscus moscheutos moscheutos*) occurs in 15 wetlands all along the coast of Lakes Erie and St. Clair and the Detroit River. The southern pond lily (*Nuphar advena*) is encountered in 12 wetlands from the Detroit River along Lake Erie and in those along the Lake Ontario coast in the Niagara Peninsula. A number of species have distributions centred on Lake Ontario and are discussed later in that context.

Ordination and Classification

Principal components analysis

Principal components analysis was applied to a matrix of data on 80 wetland sites composed of 36 variables (see Table 2). Some were continuous variables; others were categorical, taking the value 1 or 0, i.e. present or not present. These variables included interspersion and open-water classifications (see Environment Canada and OMNR 1984) as well as the presence of particular plant species, genera, or families as dominants. These variables are listed in the bottom portion of Table 2 (also see Methods of Analysis).

Classification and ordination are both used to examine patterns of variation in ecological communities. The data used in each are similar but the products are quite different. Classification creates statistically based discrete categories. Ordination derives continuous multivariate statistical models of the predominant underlying ecological gradients. The techniques offer

TABLE 2. Principal components analysis of data for 80 coastal wetlands. Factor pattern after varimax rotation. Only loadings >0.35 are shown.

Variable	Principal component 1	2	3	4
Degree-days	−0.675			
% mineral soils		−0.751		−0.361
% organic soils		0.744		−0.360
% fen	0.622		−0.356	
% swamp	0.352	0.656		
% marsh	−0.570	−0.498	0.375	
% isolated and palustrine	0.447			
% riverine		−0.447		
% riverine rivermouth				0.444
% lacustrine rivermouth			0.444	
% protected bay		0.629		
Total dissolved solids				0.681
Vegetation communities				
One form			0.387	
Two forms	0.776		0.365	
Three forms	0.796			
Four forms	0.879			
Five forms	0.813			
Six or more forms	0.514			
Interspersion				
Type 1			−0.477	
Type 2			0.540	
Type 3		0.513		−0.366
Open-water pattern				
Type 1			−0.454	
Type 2 or 3	0.431	0.362		
Type 4			0.397	
Typha	−0.710			
Scirpus	0.383		0.353	
Cyperaceae	0.665			
Juncaceae	0.601			
Larix	0.868			
Thuja	0.903			
Myrica	0.545			
Sarracenia	0.434			
Potentilla	0.642			
Myriophyllum				0.426
Sparangium				0.742
Acer		0.385		
Fraxinus		0.396		
Alnus		0.385		

different descriptions of the same ecological variation. Thus, there are common themes and parallels between the cluster analysis and principal components analysis performed in this study.

The major gradients of variation in coastal wetlands are described by the axes of the principal components analysis (Table 2; Fig. 9). The first axis represents a gradient of climate and vegetation complexity. It primarily separates the wetlands of the Bruce Peninsula from all others (Fig. 9). The occurrence of taxa such as *Thuja, Larix, Saracenia, Potentilla*, Cyperaceae, and Juncaceae are important in defining this first axis, as is the percentage of fen habitat (Table 2). Vegetation complexity is also linked to this axis; the vegetation of wetlands of the Bruce Peninsula is in general more complex structurally than that of other coastal wetlands (Table 2). The percentage of marsh habitat, presence of *Typha* as a dominant, and the number of growing degree-days are all negatively associated with the first axis (Table 2).

The second axis separates lacustrine wetlands on sheltered bays that possess large swamp components and a large proportion of organic soils. Most of these are along Lake Ontario (Table 2). The percentage area with organic soils, swamp habitat, and sheltered bay location contributes most to the second principal component (Table 2). The presence of *Acer, Fraxinus*, and *Alnus* also contributes to that axis. It thus suggests a disturbance gradient.

The third axis separates lakeside and rivermouth marshes with simple vegetation structure (Table 2). Principal component 4 suggests a productivity gradient, loading highly on dissolved solids, mineral soils, and rivermouth location (Table 2). Burreed (*Sparganium*) and milfoil (*Myriophyllum*) are the taxa associated with this axis.

These major gradients are similar to those observed in other studies of wetland vegetation (Walker and Wehrhahn 1971; Hutchinson 1975; Keddy 1983; Nilsson 1987; Day et al. 1988). The fertility, disturbance, and water depth gradients so often observed in wetland vegetation are evident in this study. The sampling units in this study are composite wetland units of varying sizes and thus may obscure finer scale variation. Furthermore, only relatively imprecise measures of disturbance and water depth were available to quantify those gradients.

Cluster analysis

Wetland classification can be theoretic, distinguishing between wetland class, form, and type based on general principles (Cowardin et al. 1979; Environment Canada 1987), or empirical based on measured statistical similarity. Two recent initiatives of a theoretic nature are the classification of Great Lakes aquatic habitats (Sly and Busch 1988) and development of a coastal habitat classification for setting conservation priorities (Smith 1987, 1989). The empirical classification developed here will be of use in both initiatives.

The tree diagram derived from cluster analysis of the physical structure (Fig. 10) includes soils, vegetation complexity, and dominant plant species of 80 different wetlands. The variables used are those listed in Table 2, as well as presence–absence of other dominant species (see Methods of Analysis). Ten categories result from the cluster analysis. The major characteristics of the 10 categories are shown in Table 3. Vegetation complexity, site type, and species composition appear to be the important influences on clustering.

The first two major divisions or "branches" in the cluster analysis (groups A, B, and C) (Figure 10; Table 3) isolate riverine wetlands with relatively simple marsh vegetation communities and predominantly mineral soils from other types of wetlands. Group A includes Hoople Creek on the St. Lawrence, Cedar Creek at the west end of Lake Erie, and Jordan Harbour and Eight Mile Creek from the Niagara shoreline of Lake Ontario. Particularly high levels of dissolved solids characterize these wetlands (Table 3). All are subject to considerable runoff from agricultural areas. In group B are a series of small, rivermouth *Typha* marshes from the St. Lawrence and Lakes Ontario and Erie (Table 3). These have very simple vegetation

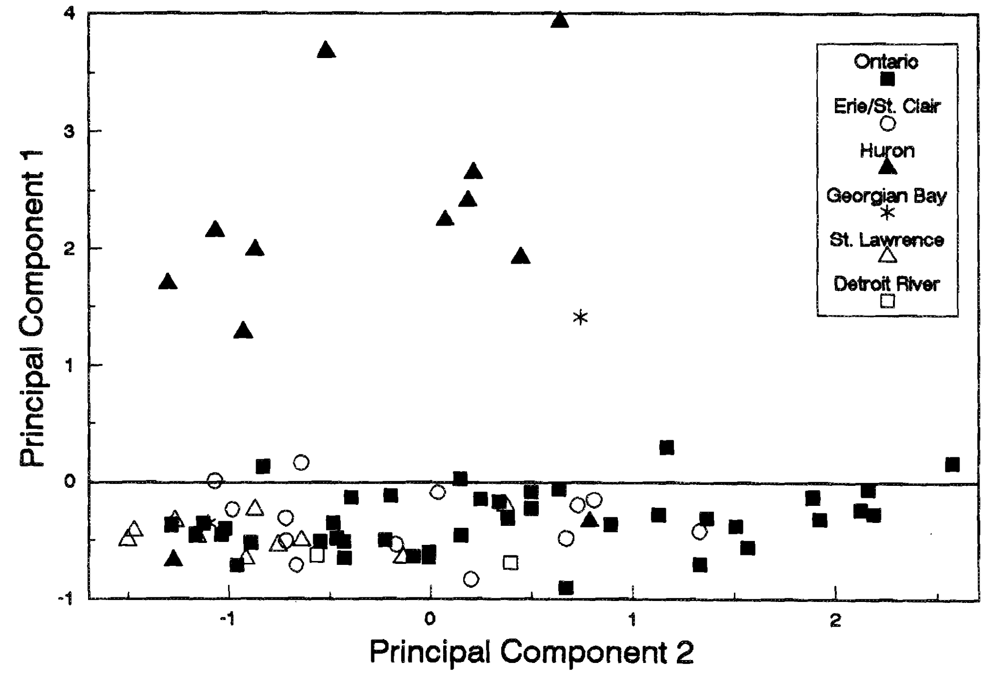

FIG. 9. Two-dimensional ordination of 80 coastal wetlands using principal components analysis. Table 2 indicates the variables contributing to the first two principal components.

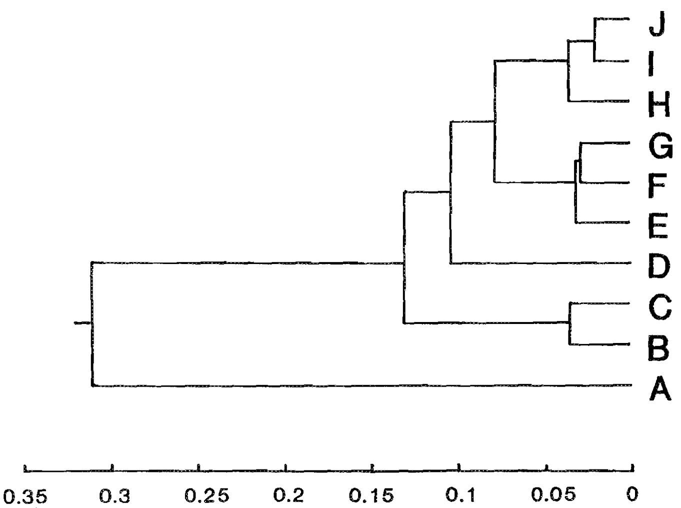

FIG. 10. Tree diagram of the groups derived in a cluster analysis of the physical and vegetation structure and plant species composition of 80 coastal wetlands along the Great Lakes and St. Lawrence River. Letters identify particular categories described in the text and Table 3.

communities. St. Lawrence wetlands and a few others make up group C (Fig. 10), which are predominantly *Typha* marshes with areas of submergents and floating plants such as *Nuphar* as well as occasional swamp components dominated by *Salix*.

Wetlands on protected bays form group D (Table 3). Consequently, the substrates here are on average 85% covered by organic soil, and swamp habitat of *Salix*, *Acer*, and *Fraxinus* make up an average of 35% of the wetland area. Dissolved solids are also generally high. This group could thus be characterized as subject to low levels of disturbance.

Groups E–J (Fig. 10; Table 3) generally have much more complex vegetation structure. Group E wetlands are generally predominantly *Typha* marshes with some communities dominated by *Scirpus*, *Nuphar*, *Nymphaea*, and *Myriophyllum*. They also often possess a swamp component composed of *Salix*, *Cornus*, *Acer*, *Fraxinus*, and *Alnus*. This diversity of species and life forms suggests a large range in water depth for both swamps and marshes. Most lacustrine wetlands fall into group F, primarily those of Lake Ontario, such as Presqu'ile Marshes, but also Kettle Point and Fishing Islands on Lake Huron (Table 3). Many of these wetlands are relatively large. Their marshes contain *Typha*, *Scirpus*, Poaceae, and Cyperaceae. The exposed lacustrine location accounts for this species composition. *Typha* is known to predominate in sheltered locations, while Cyperaceae, Juncaceae, and Poaceae are found in more exposed sites with greater water depth (Hutchinson 1975). *Salix* and *Fraxinus* generally dominate the small adjacent swamps, although *Larix* and *Thuja* occur at the Fishing Islands.

The shoreline fens of Lake Huron and Georgian Bay constitute group G (Table 3). Predominantly lacustrine, these sites also often contain a palustrine component. The vegetation is decidedly northern in affinity (also see Reddoch 1982; Charlton 1986; Charlton and Hilts 1989) with Cyperaceae, Juncaceae, *Thuja*, *Larix*, *Sarracenia*, *Potentilla*, and *Myrica gale* as well as the more typical *Salix* and *Cornus*. *Typha* is not a dominant and is generally absent.

Riverine and rivermouth wetlands with a high percentage of organic soils and complex vegetation structure form group H (Fig. 10; Table 3). These wetlands are located along the Detroit and St. Clair Rivers or along rivers emptying into one of the lakes.

Wetlands with a large percentage of isolated and palustrine site type fall into group I (Fig. 10; Table 3). These include two Bruce Peninsula wetlands and Nut Island Duck Club wetland on Amherst Island, Lake Ontario. The latter contains one of the two coastal bogs among the entire 160 wetlands evaluated.

TABLE 3. Characteristics of categories (A–J) of cluster analysis (see Fig. 10). Mean values are given except for number in category and dominant taxa.

Variable/descriptor	A Rivermouth	B Simple riverine	C St. Lawrence	D Protected bays	E *Typha*	F Lacustrine	G Shoreline fens	H Organic soils	I Palustrine component	J Protected bays
Number in category	4	5	14	7	9	7	9	8	4	9
% organic soil	2.5	0.0	11.1	85.2	31.7	60.8	15.4	84.6	84.7	97.2
Dissolved solids (mg/L)	580	299	186	371	219	181	249	214	198	235
Wetland type										
% marsh	83.5	96.6	93.1	64.5	87.2	87.5	53.0	75.0	53.2	65.9
% swamp	16.5	3.4	6.9	35.5	12.4	11.7	25.7	22.6	41.5	33.1
% fen							20.7	2.4	5.4	
Site type										
% palustrine		11.0	2.3	11.8	1.1		20.8	3.0	30.7	14.4
% riverine	62.3	64.0	95.0	10.3	10.4	3.0	3.1	81.3	4.8	2.2
% rivermouth	37.7	25.0	2.7	1.4	35.2	2.1	1.2	14.3	1.4	1.1
% lacustrine				12.6	11.1	90.9	69.7	1.4	0.7	
% protected bay				63.9	42.2	4.0	3.5		13.3	82.2
Vegetation attributes										
No. of vegetation communities	9.0	4.4	9.1	8.7	14.3	17.1	24.3	11.6	30.0	9.3
Dominant taxa	*Typha, Salix*	*Typha*	*Typha, Nuphar, Salix*	*Typha, Salix, Acer, Fraxinus*	*Typha, Scirpus, Nuphar, Nymphaeae, Salix, Cornus*	*Typha Scirpus,* Poaeaceae, Cyperaceae, *Salix, Fraxinus*	Cyperaceae, Juncaceae, *Thuja, Larix, Sarracenia*	*Typha, Nuphar, Salix*	Cyperaceae, *Cornus, Salix*	*Acer, Salix*

Group J is similar to group D in having locations on protected bays and high percentages of organic soils and swamp habitat (Table 3). However, group J has a more complex pattern in the spatial arrangement of the vegetation communities or interspersion (see Environment Canada and OMNR 1984).

Conclusions

Our study, drawn from detailed assessment of Ontario's Great Lakes coastal wetlands under the Ontario wetland evaluation system, provides the first summary of important physical and ecological attributes for this coastal wetland habitat. Many patterns reflected in this study corroborate the results of other research on shoreline wetlands and Great Lakes wetlands in particular. The major role of coastal geomorphology and exposure in defining wetland form is known from other studies (e.g. Herdendorf 1987). The presence of disturbance and fertility gradients is typical in shoreline wetland vegetation (Hutchinson 1975; Day et al. 1988). The climatic gradient observed is generally recognized at a biogeographic scale (Whillans 1987). However, the large geographic scale of this study allowed the quantification of the climatic gradient.

Many of these coastal wetlands are class 1 and 2 (provincially significant) or class 3 (regionally significant). Our analyses will be useful to current binational efforts to categorize Great Lakes habitats under the Classification and Inventory of Great Lakes Habitats (CIGLAH) program. They will also assist nongovernmental initiatives to identify and protect critical unprotected coastal habitats. Moreover, our findings contribute to the general ecological knowledge of Ontario's coastal wetlands and suggest areas for further research.

Acknowledgements

We wish to thank all those in OMNR district and regional offices, Environment Canada, and the Conservation Authorities who have assisted in the wetland evaluation effort. In particular we thank John Archbold, Abbe Edelson, Roger Whitwam, Carol-Ann Itel, Ann Misetich, Alex Arifuzzaman, and Amy Stein for technical assistance. Dr. Paul Keddy provided helpful comments on the manuscript.

References

ARGUS, G. W., K. PRYOR, D. J. WHITE, AND C. KEDDY. 1982–88. Atlas of the rare vascular plants of Ontario. Botany Division, National Museum of Natural Sciences, Ottawa, Ont.

AUCLAIR, A. N., A. BOUCHARD, AND J. PAJACZKOWSKI. 1976. Plant standing crop and productivity relations in a *Scirpus–Equisetum* wetland. Ecology 57: 941–952.

BARDECKI, M. J. 1981. Wetland conservation policies in Southern Ontario: a delphi approach. Ph.D. thesis, Department of Geography, York University, Toronto, Ont.

BIRD, E. C. F. 1984. Coasts: an introduction to coastal geography. Basil Blackwell, New York, NY. 320 p.

BLOKPOEL, H. 1977. Gulls and terns nesting in northern Lake Ontario and the upper St. Lawrence River. Can. Wildl. Serv. Prog. Notes No. 75.

BLOKPOEL, H., AND G. MCKEATING. 1978. Fish-eating birds nesting in Canadian Lake Erie and adjacent waters. Can. Wildl. Serv. Prog. Notes No. 87.

BROWNELL, V. R., AND M. J. OLDHAM. 1983. Status report on the bald eagle (*Haliaeetus leucocephalus*) in Canada. Nongame Program Wildlife Branch, Ontario Ministry of Natural Resources, Toronto, Ont.

CADMAN, M., P. EAGLES, AND F. HELLEINER [ED.] 1987. The Ontario breeding bird atlas. University of Waterloo Press, Waterloo, Ont.

CAMPBELL, C. A., B. W. EVERED, D. W. PERIN, M. C. SHARP, AND B. B. WELLER. 1981. The Great Lakes biogeographic province: a Canadian review of source material. The Nature Conservancy of Canada, Toronto, Ont. 2 vol.

CAMPBELL, R. R. 1984. Rare and endangered fishes and marine mammals of Canada: the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) fish and marine mammals subcommittee. Can. Field Nat. 98: 71–74.

1985. Rare and endangered fishes and marine mammals of Canada: (COSEWIC) fish and marine mammals subcommittee status reports: II. Can. Field Nat. 99: 404–408.

CHAPMAN, L., AND D. PUTNAM. 1984. The physiography of southern Ontario. 3rd ed. Spec. Vol. 2. Ontario Geological Survey, Toronto, Ont.

CHARLTON, D. 1986. Ecological studies of Bruce Peninsula wetlands: classification of fens and related wetland types. M.Sc. thesis, Department of Land Resource Science, University of Guelph, Guelph, Ont.
CHARLTON, D. L., AND S. HILTS. 1989. Quantitative evaluation of fen ecosystems on the Bruce Peninsula. Proceedings of the Second Ontario Wetlands Conference. Federation of Ontario Naturalists, Toronto, Ont.
CHRISTIE, W. 1973. A review of the changes in the fish composition of Lake Ontario. Great Lakes Fish. Comm. Tech. Rep. No. 23.
COLLINS, B., AND L. MALTBY. 1984. A statistical analysis of "an evaluation system for wetlands of Ontario, first edition (1983)." Canadian Wildlife Service, Ottawa, Ont.
COWARDIN, L., V. CARTER, F. GOLET, AND E. LAROE. 1979. Classification of wetland and deepwater habitats of the United States. U.S. Fish Wildl. Serv. Publ. FWS/OBS-79/31, Washington, DC.
CROWDER, A. A., AND J. M. BRISTOW. 1988. The future of waterfowl habitats in the Canadian lower Great Lakes wetlands. J. Great Lakes Res. 14: 115–127.
CROWDER, A., B. MCLAUGHLIN, R. WEIR, AND W. CHRISTIE. 1986. Shoreline fauna of the Bay of Quinte, p. 190–200. *In* C. Minns, D. A. Huley, and K. Nichols [ed.] Project Quinte: point-source phosphorus control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Special Publ. Fish. Aquat. Sci. 86: 270 p.
DAY, R. T., P. A. KEDDY, J. MCNEILL, AND T. CARLETON. 1988. Fertility and disturbance gradients: a summary model for riverine marsh vegetation. Ecology 69: 1044–1054.
DENNIS, D., AND R. CHANDLER. 1974. Waterfowl use of the Ontario shoreline of the southern Great Lakes during migration, p. 58–65. *In* H. Boyd [ed.] Canadian Wildlife Service waterfowl studies in Eastern Canada. Can. Wildl. Serv. Rep. Ser. No. 29.
DENNIS, D., G. MCCULLOUGH, N. NORTH, AND R. ROSS. 1984. An updated assessment of migrant waterfowl use of the Ontario shorelines of the southern Great Lakes, p. 37–42. *In* S. Curtis, D. Dennis, and H. Boyd [ed.] Waterfowl studies in Ontario, 1973–81. Can. Wildl. Serv. Occas. Pap. No. 54.
DENNIS, D., AND N. NORTH. 1984. Waterfowl use of the Lake St. Clair marshes during migration in 1968–69, 1976–77 and 1982, p. 43–52. *In* S. Curtis, D. Dennis, and H. Boyd [ed.] Waterfowl studies in Ontario, 1973–81. Can. Wildl. Serv. Occas. Pap. No. 54.
DRAPER, N., AND V. SMITH. 1984. Applied regression analysis. 2nd ed. Wiley, New York, NY.
ENVIRONMENT CANADA. 1985. Wetlands of the St. Lawrence River region, 1950–1975. Working Pap. No. 45. Lands Directorate, Ottawa, Ont.
1987. The Canadian wetland classification system. Classif. Ser. No. 21.
ENVIRONMENT CANADA AND ONTARIO MINISTRY OF NATURAL RESOURCES. 1984. An evaluation system for wetlands of Ontario south of the precambrian shield. 2nd ed.
FAHSELT, D., AND M. A. MAUN. 1980. A quantitative study of shoreline marsh communities along Lake Huron in Ontario. Can. J. Plant Sci. 60: 669–678.
FRANCIS, G. R., J. J. MAGNUSON, H. A. REGIER, AND D. R. TALHELM. [ED.] 1979. Rehabilitating Great Lakes ecosystem. Great Lakes Fish. Comm. Tech. Rep. No. 37.
GAUCH, H. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge, U.K. 298 p.
GLOOSCHENKO, V. 1983. Development of an evaluation system for wetlands in Southern Ontario. Wetlands 3: 192–200.
1985. Characteristics of provincially significant wetlands as assessed by the Ontario Wetland Evaluation System, p. 187–199. *In* H. Prince and F. D'Itri [ed.] Coastal wetlands. Lewis Publ. Inc., Chelsea, MI.
GLOOSCHENKO, V., J. H. G. ARCHBOLD, AND D. HERMAN. 1988a. The Ontario wetland evaluation system: replicability and bird habitat selection, p. 115–127. *In* D. D. Hook [ed.] The ecology and management of wetlands. Vol. 2. Croom Helm Ltd., Beckenham, Kent, U.K.
GLOOSCHENKO, V., J. ARCHBOLD, AND J. WENINGER. 1987. The importance of swamp wetland habitat in southern Ontario, p. 275–285. *In* C. Rubec and R. Overend [ed.] Proceedings Symposium '87 Wetlands/Peatlands. International Peat Society, National Wetlands Working Group, Canadian Horticultural Peat Harvesters Industry, and Environment Canada, Ottawa, Ont.
GLOOSCHENKO, V., B. PARKER, L. COO, R. KENT, C. WEDELES, A. MASON, J. DAWSON, D. HERMAN, AND P. SMITH. 1988b. Provincially and regionally significant wetlands in southern Ontario. Interim report 1987. Wildlife Branch, Ontario Ministry of Natural Resources, Toronto, Ont.
GOODYEAR, C. D., T. EDSALL, D. ORMSBY DEMPSEY, G. D. MOSS, AND P. POLANSKI. 1982. Atlas of the spawning and nursery areas of the Great Lakes fishes. U.S. Fish Wildl. Serv. Publ. FWS/OBS-82/52, Washington, DC.
GUIRE, K., AND E. VOSS. 1963. Distributions of distinctive shoreline plants in the Great Lakes region. Mich. Bot. 2: 99–114.
HERDENDORF, C. E., S. HARTLEY, AND M. BARNES. 1981. A summary of knowledge of the fish and wildlife resources of the coastal wetlands of the U.S. Great Lakes. Center for Lake Erie Area Research, Ohio State University, Columbus, OH.
HERDENDORF, C. E. 1987. The ecology of the coastal marshes of western Lake Erie: a community profile. National Wetlands Research Center. U.S. Fish Wildl. Serv. U.S. Dep. Inter. Biol. Rep. 85(7.9).
HERDENDORF, C. E., C. N. RAPHAEL, AND E. JAWORSKI. 1986. The ecology of Lake St. Clair wetlands: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.7): 187 p.
HUTCHINSON, G. E. 1975. Limnological botany. Vol. 3. A treatise on limnology. John Wiley and Sons, New York, NY.
KEDDY, C., AND P. KEDDY. 1984. Reproductive biology and habitat of *Cirsium pitcheri*. Mich. Bot. 23: 57–67.
KEDDY, P. A. 1983. Shoreline vegetation in Axe Lake, Ontario: effects of exposure on zonation patterns. Ecology 64: 331–344.
KEDDY, P. A., AND A. A. REZNICEK. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. J. Great Lakes Res. 12: 25–36.
KING, R. 1986. Population ecology of the Lake Erie water snake *Nerodia sipedon insularum*. Copeia 1986: 757–772.
LACOURSIERE, E. 1969. Étude écologique de la végétation riparienne entre Sainte-Famille et la Pointe d'Argentenaye à l'île d'Orléans. M.A. thesis, Faculty of Forestry and Geodesy, Laval University, Quebec, Que. 150 p.
LEMAY, M., AND G. MULAMOOTTIL. 1984. A study of changing land uses in and around Toronto Waterfront marshes. Urban Ecol. 8: 313–328.
MCALLISTER, D. E., B. J. PARKER, AND P. M. MCKEE. 1985. Rare, endangered and extinct fishes in Canada. Syllogeus 54.
MCCULLOUGH, G. 1981. Wetland losses in Lake St. Clair and Lake Ontario, p. 81–89. *In* A. Champagne [ed.] Proceedings of the Ontario Wetlands Conference. Federation of Ontario Naturalists, Toronto, Ont.
1985. Wetland threats and losses in Lake St. Clair, p. 201–208. *In* H. Prince and F. D'Itri [ed.] Coastal wetlands. Lewis Publ. Inc., Chelsea, MI.
MORTON, J. 1979. Observations on Houghton's goldenrod (*Solidago houghtonii*). Mich. Bot. 18: 31–35.
MUELLER-DOMBOIS, D., AND H. ELLENBERG. 1974. Aims and methods of vegetation ecology. Wiley, New York, NY.
NILSSON, C. 1987. Distribution of stream-edge vegetation along a gradient of current velocity. J. Ecol. 75: 513–522.
OLDHAM, M. J. 1983. An update on the status of the blue racer (*Coluber constrictor foxi*), Lake Erie water snake (*Nerodia sipedon insularum*), Blanchard's cricket frog (*Acris crepitans blanchardi*), and smallmouth salamander (*Ambystoma texanum*) on Pelee Island, Ontario. Wildlife Branch, Ontario Ministry of Natural Resources, Toronto, Ont.
ONTARIO MINISTRY OF NATURAL RESOURCES. 1984. Guidelines for wetlands management. Toronto, Ont.
1987. Guidelines for the preparation of shoreline management plans. Conservation Authorities and Water Management Branch, Toronto, Ont.
PATTERSON, N. J. 1984. An approach to wetland evaluation and assessing cultural stresses on freshwater wetlands in southern Ontario. M.Sc. thesis, I.E.S., University of Toronto, Toronto, Ont. 192 p.
PIELOU, E. 1984. Interpretation of ecological data: a primer on classification and ordination. Wiley, Toronto, Ont.
REDDOCH, J. 1982. Southern Ontario fens. Plant Press 1: 76–78.
REID, R. 1981. A critic's view of wetland policies, p. 98–107. *In* A. Champagne [ed.] Proceedings of the Ontario Wetlands Conference. Federation of Ontario Naturalists, Toronto, Ont.
REID, R. A., N. PATTERSON, L. ARMOUR, AND A. CHAMPAGNE. 1980. A wetland evaluation model for S. Ontario. Federation of Ontario Naturalists, Toronto, Ont. 140 p.
ROSS, R. 1984. Migrant waterfowl use of the major shorelines of eastern Ontario, p. 53–62. *In* S. Curtis, D. Dennis, and H. Boyd [ed.] Waterfowl studies in Ontario, 1973–81. Can. Wildl. Serv. Occas. Pap. No. 54.
SEMPLE, C. J., AND G. S. RINGIUS. 1983. Goldenrods of Ontario, *Solidago* and *Euthamia*. Univ. Waterloo Biol. Ser. 26: 84 p.
SLY, P. G., AND W-D. N. BUSCH. 1988. A system for aquatic habitat classification of lakes. Great Lakes Fishery Commission, Ann Arbor, MI.
SMITH, P. G. R. 1987. Towards the protection of Great Lakes natural heritage areas. Tech. Pap. No. 2. Heritage Resources Centre, University of Waterloo, Waterloo, Ont. 164 p.

——— 1989. Wetlands on the edge: coastal management and Great Lakes coastal wetlands. Proceedings of the Second Ontario Wetlands Conference. Federation of Ontario Naturalists, Toronto, Ont. 8 p.

SNELL, E. A. 1982. An approach to mapping the wetlands of southern Ontario. *In* M. J. Bardecki [ed.] Proceedings, Preconference Session, Ontario Wetland Conference. Occassional Paper. Department of Applied Geography, Ryerson Polytechnical Institute, Toronto, Ont.

——— 1987. Wetland distribution and conversion in southern Ontario. Inland Waters/Lands Directorate, Environment Canada. Working Paper No. 48, Ottawa, Ontario.

STEELE, R., AND J. TORRIE. 1980. Principles and procedures of statistics. A biometrical approach. McGraw-Hill, New York, NY.

STEPHENSON, T. D. 1988. Fish utilization of Toronto area coastal marshes. M.Sc. thesis, University of Toronto, Toronto, Ont.

——— 1989. Significance of Toronto area coastal marshes for fish. Proceedings of the Second Ontario Wetlands Conference. Federation of Ontario Naturalists, Toronto, Ont.

WALKER, B. H., AND C. F. WEHRHAHN. 1971. Relationships between derived vegetation gradients and measured environmental variables in Saskatchewan wetlands. Ecology 52: 85–95.

WESELOH, D., P. MINEAU, S. TEEPLE, H. BLOKPOEL, AND B. RATCLIFF. 1986. Colonial waterbirds nesting in Canadian Lake Huron in 1980. Can. Wildl. Serv. Prog. Notes.

WHILLANS, T. H. 1982. Changes in marsh area along the Canadian shore of Lake Ontario. J. Great Lakes Res. 8: 570–577.

——— 1987. Wetlands and aquatic resources, p. 321–356. *In* M. C. Healy and R. R. Wallace [ed.] Canadian aquatic resources. Can. Bull. Fish. Aquat. Sci. 215: 533 p.

WHITCOMB, M., R. NARRIS, AND R. CARLISLE. 1973. Prince Edward County. Environmental Planning Series, Miscellaneous Report, Parks Planning Branch, Ministry of Natural Resources, Toronto, Ont.