

# Rates of natural and anthropogenic change in shoreline habitats in the Kingston Basin, Lake Ontario

A.A. Crowder, J.P. Smol, R. Dalrymple, R. Gilbert, A. Mathers, and J. Price

**Abstract:** Shoreline habitats in the Kingston Basin have experienced continual change on a wide range of time scales, as a result of physical, chemical, and biotic stresses of both natural and anthropogenic origin. Not all change can or should be controlled. From a management perspective, stresses can be usefully subdivided into those that originate from the lake as a whole (e.g., water-level and-chemistry changes, introduction of exotic species) and those originating from the adjacent land area (e.g., point-source contamination and sedimentation). Stresses from the lake cannot be controlled locally, whereas those arising from terrestrial activities are more easily managed. Slow rates of change are less likely to have dramatic effects than rapid change, but a small change can have catastrophic effects if it exceeds the threshold tolerance of an ecosystem. Dramatic alterations to the entire ecosystem can also occur if a single, important species (e.g., a macrophyte) is adversely affected, because of complex feedback responses between the various components of the system. Thus, management strategies should focus on those areas that are particularly susceptible to land-based stress and on stresses that are most likely to exceed the tolerance of key components of an ecosystem.

**Résumé :** Les habitats des rivages du bassin de Kingston ont connu des changements continus pendant une vaste gamme d'échelles temporelles à cause d'agressions physiques, chimiques et biotiques d'origine naturelle et humaine. Toutefois, il n'est pas possible ou souhaitable de limiter tous ces changements. Sur le plan de la gestion, on peut subdiviser utilement ces stress en deux catégories, soit ceux qui proviennent de l'ensemble du lac (p. ex. les changements du niveau et de la chimie de l'eau, l'introduction d'espèces exotiques) et ceux qui proviennent des terres adjacentes (p. ex. la contamination due à des sources ponctuelles et la sédimentation). Il n'est pas possible de limiter à l'échelle locale les stress dus à l'ensemble du lac mais, par contre, ceux qui proviennent d'activités terrestres sont plus faciles à gérer. Les changements lents auront vraisemblablement des effets moins marqués que les changements rapides, mais un petit changement peut avoir des effets catastrophiques s'il dépasse le seuil de tolérance d'un Écosystème. On peut également noter de fortes altérations de tout un écosystème si une espèce unique, mais importante (p. ex., un macrophyte) est perturbée, à cause de rétroactions complexes entre les différents éléments du système. Par conséquent, les stratégies de gestion doivent porter plus spécialement sur les zones qui sont particulièrement sensibles aux stress provenant des terres voisines et à ceux qui ont le plus de chances de dépasser le seuil de tolérance de composants clés d'un écosystème.

[Traduit par la Rédaction]

## Introduction

The aim of this paper is to focus the attention of managers who are responsible for conservation or enhancement of coastal habitats on (i) the mutability of these habitats and (ii) rates of change of ecosystem processes in them. The types of managerial actions likely to be undertaken, including structural, chemical, or biotic alterations, are discussed by Geiling et al.

(1996) in this issue. If a habitat is changing rapidly, should resources be used for its conservation or enhancement? Are coastal habitats, to use the terms of this workshop's introduction, "constant and continuing?" Can stresses likely to prevent conservation be detected in these areas?

The region selected for discussion is the Kingston Basin of Lake Ontario (Fig. 1). It includes the lake shore and the estuarine portions of the rivers entering the Basin. The boundary between aquatic and terrestrial ecosystems is well defined along most of the shore, but is often diffuse in wetlands; cottage lots and marshes, for example, form a vegetational continuum in some parts of the basin (McLaughlin 1993). Before examining changes, the present types of shoreline in the Kingston Basin are described and their geological age is briefly discussed.

The term "habitat" is used to define both the area used by a particular species, such as "pike habitat," and a type of environment, such as a "cattail marsh" or a "sandy bay." The first usage can cause difficulties because of the overlapping use of an area by different groups and species of organisms. Some species remain in a particular habitat all their lives, while others move through wide geographic areas and use several

Received November 1994. Accepted December 13, 1995.  
J13224

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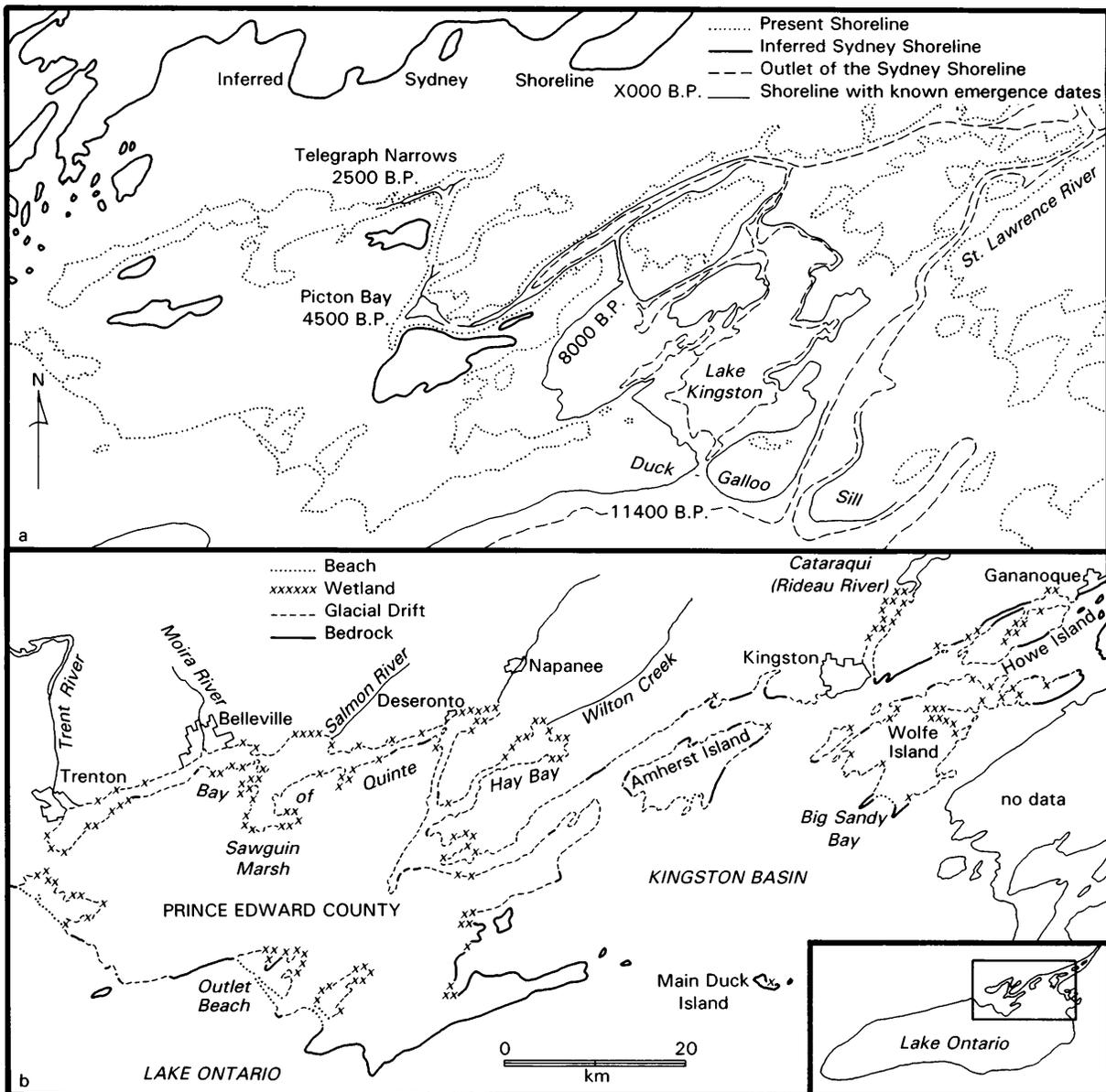
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**Fig. 1.** (a) Development of the Kingston Basin, with the present shoreline shown by a dotted line. The Sydney shoreline in the north preceded the 11 400 yr BP phase, which had an outlet indicated by a broken line. Where dates are known for younger portions of the shore these are shown. (b) The distribution of beach, wetland, glacial drift (till), and bedrock on the shores of the Kingston Basin, which is also shown in the inset.



types of site. In this volume, Geiling et al. (1996) develop a model of fish habitat based on three components, physical, chemical, and biotic, which vary through space and time. We use examples of these three components to examine temporal changes in coastal habitats in the Kingston Basin. To discuss changes in physical components we have selected water levels and sedimentation (sections A and B). For the chemical component we have selected acidity, salinity, nutrient status, and contamination (sections C, D, E, and F). To discuss changes in the biotic component we have selected communities of algae, macrophytes, fish, reptiles and amphibians, and piscivorous birds (sections G, H, I, J, and K). Rates of introduction of exotic species are discussed in Section L. Where possible,

interactions between the three types of component are emphasized.

A change in any of these components will impose a stress on an ecosystem. Depending on the magnitude and rate of change, the ecosystem responds to that stress in one of five ways (Keith 1994): (i) the ecosystem continues to function but with "hiccups"; (ii) it continues to function but at a lower level, for example, of diversity or productivity; (iii) it incorporates new features, such as exotic species; (iv) it functions, but differently; or (v) it collapses without regeneration.

Which of these ecosystem changes are apparent in modern and past habitats in the Kingston Basin? Do the coastal wetlands or the nearshore zone exhibit cycles of aging and enju-

vention, which have been postulated for some fish communities (Sly 1991)? Do they exhibit slow and steady changes, or do they reach threshold values followed by catastrophic events (Minns et al. 1986)? While these questions have previously been considered in the context of Lake Ontario as a whole (Christie 1973; Sly 1991; Stoermer 1993), attention has not previously been focussed on changes in nearshore habitats.

### **Description of shoreline habitats in the Kingston Basin**

The lengths of different types of shoreline were abstracted from the Coastal Zone Atlas (for types cf. Cowardin et al. 1979; Geis 1985). The largest component (by length of shoreline) is glacial drift or till (57%), followed by bedrock (21%), wetlands (15%), and beaches (5%). The balance (2%) includes docks, marinas, etc. Comment on these types of shoreline follows, giving some named examples and references. Locations are shown in Fig. 1.

Bedrock is Palaeozoic limestone in the west and mostly Precambrian Shield rocks east of Kingston. The rock areas include large cliffs, which are excluded from discussion here (e.g. Main Duck Island, middle Bay of Quinte). Examples of gently sloping bedrock shores include parts of the Bay of Quinte (Crowder and Bristow 1986; Dushenko 1990; McLaughlin 1993), Collins Bay (Browne 1991), Deadman Bay (east of Kingston), Amherst Island and Wolfe Island (Johnston 1972, 1978), and the St. Lawrence River (Ruta 1981).

A veneer of glacial till or glaciolacustrine silt and clay covers much of the bedrock and forms steep shores in areas protected from erosion such as parts of Cataraqui Bay. Elsewhere, this sediment has been eroded and fringing beaches of sand and gravel formed from the winnowed, coarser fraction protect the remaining glacial sediments behind. Only at the highest water level do the glacial sediments come in contact with the lake.

Beach habitats generally are exposed to a long fetch facing the southwest prevailing wind, and include Presqu'île and Outlet beaches in Prince Edward County and Big Sandy Bay on Wolfe Island (Law and McKenna Neuman 1993). These beaches are favourite staging areas for migratory waterfowl (references in Crowder and Bristow 1988).

Wetlands comprise three main types: lagoons behind barrier beaches, embayed wetlands, and riverine estuaries. Wetlands behind barrier beaches occur in the same situations as beaches, e.g., on the west side of Prince Edward County and Wolfe Island, where the barriers are sand, and in sites such as Yorkshire Island on the Main Duck Sill and Prince Edward Point, where the barriers are gravel or cobbles. Barriers may be breached by storms or high water levels, allowing lake water into lagoons. The most fragile wetlands in the area are probably intradune pannes, which are habitat for some rare plants in the Prince Edward County sand dunes (Law and McKenna Neuman 1993).

Embayed wetlands occur where the form of the shore offers protection from wind and wave action. Numerous small embayed wetlands sheltered from the prevailing southwest winds have been described by Greig (1989), Dushenko (1990), and McLaughlin (1993) in the Bay of Quinte. Embayed wetlands on Wolfe Island were described by Price (1994). Embayed

wetlands are affected primarily by stresses of lake origin because of the absence of significant river influence (cf. Dalrymple et al. 1992).

Riverine wetlands occur in the lower reaches of large rivers or small creeks in the region. The Cataraqui River exemplifies their freshwater estuarine form, influenced both by river flow and lake action (Dalrymple and Carey 1990; Dalrymple and Price 1994). The estuarine nature of the river marshes is emphasized by occasional seiche-induced bores in the lower Napanee River. Sediments in the marshes include peat, gyttja, clay, and sand (Fig. 2). Following Dalrymple et al. (1992), we emphasize that estuarine wetlands are impacted by stresses derived both from Lake Ontario and from the adjacent land area.

The large river mouths have been drastically altered in the last 200 years. Dams were built on most rivers, including the Trent, Moira, Salmon, Wilton, Napanee, Cataraqui, and Gananoque systems. The mouth of the Salmon system was quarried for aggregates, creating new lagoon areas. Flow has been restricted by roads and railway embankments (e.g., in Landon Bay and in creeks from Belleville to Deseronto) and dams made for duck habitat (Mud Creek). Urbanization has "hardened" the lower banks of the major rivers, and in most cases their flow is controlled. The most valuable fish habitat now occurs in the least developed areas including Hay Bay (Wilton Creek) and Muscote Bay. Despite urbanization, however, the lower Trent River is still a walleye breeding habitat (Bay of Quinte RAP Committee 1990).

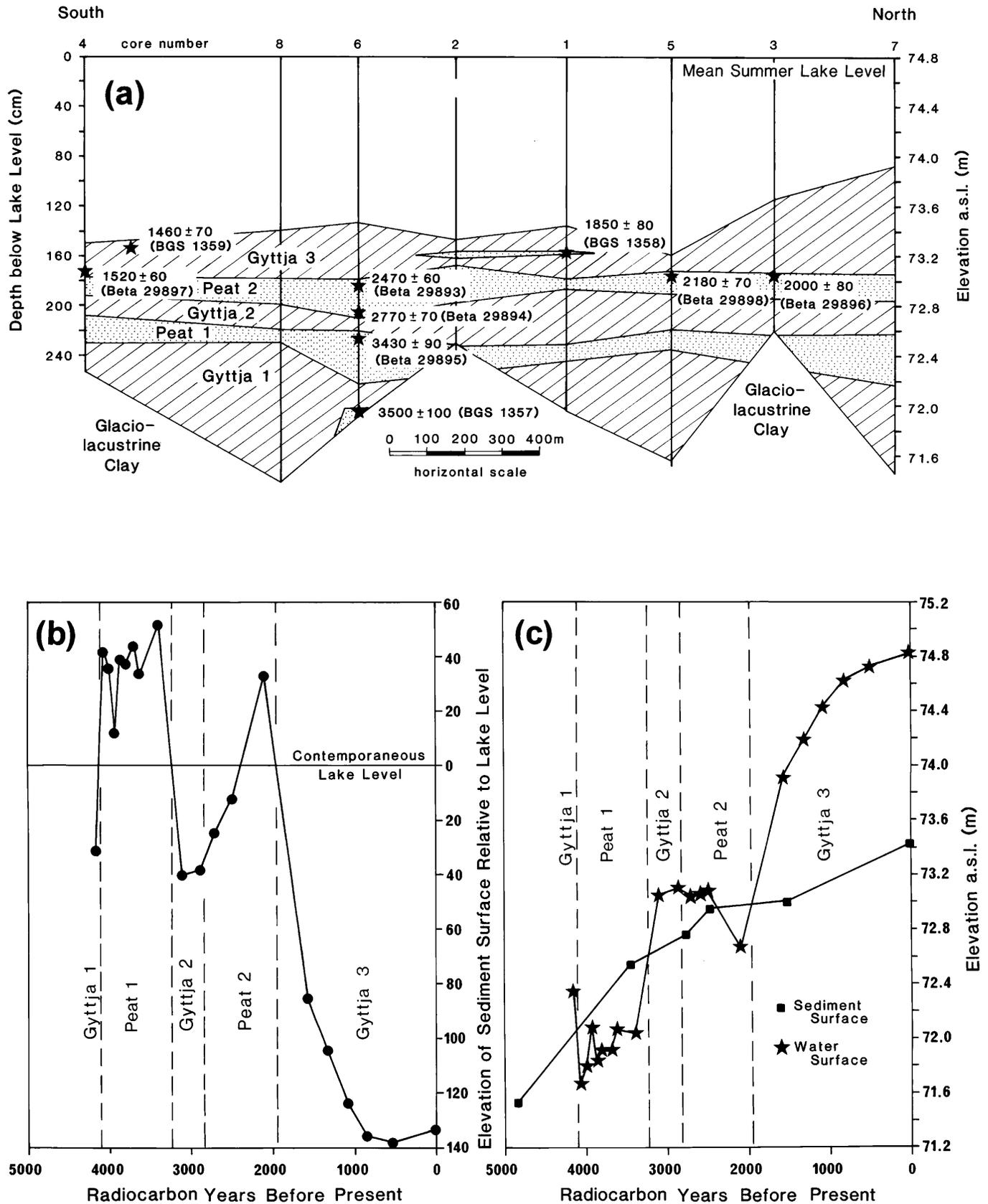
Vegetation in the wetlands includes submerged, floating, and emergent marsh types; woody shrub thickets; and swamp forests. The most widely distributed wetland vegetation type in the Kingston Basin (as distinguished from the geomorphic types described above) is cattail marsh (Crowder et al. 1977; Revill Associates 1979; Catling 1985; Crowder and Bristow 1986).

### **How old is the present shoreline?**

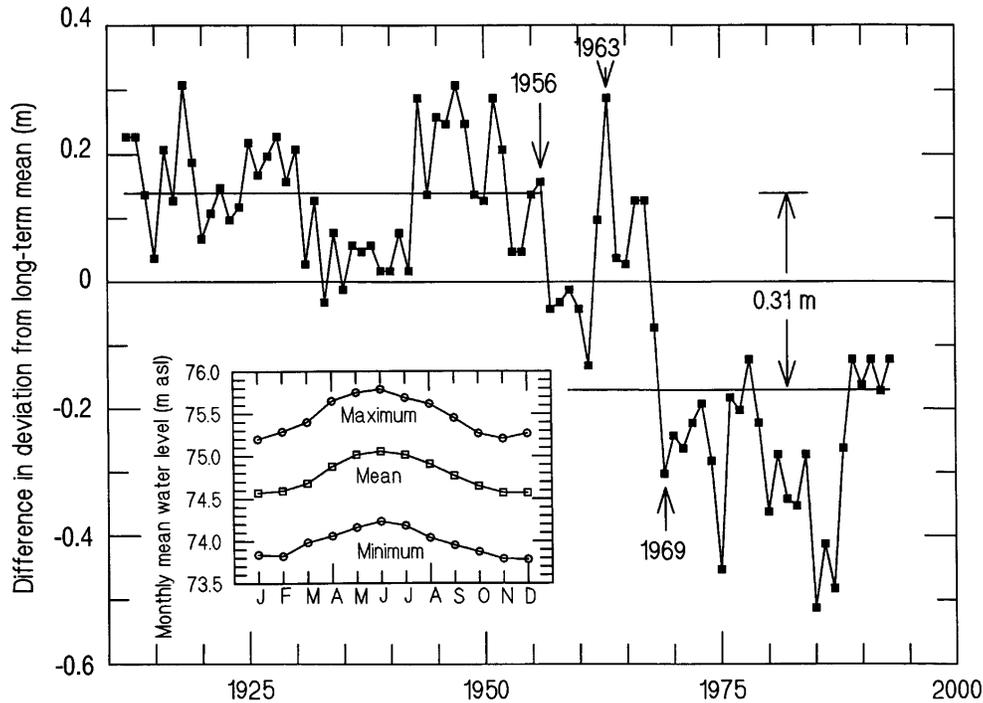
The Kingston Basin was part of glacial Lake Iroquois, which formed when retreating Laurentian ice dammed the St. Lawrence valley about 12 400 yr BP. Under harsh cold conditions, thick deposits of glaciolacustrine sediments (mainly clays in the study area) were deposited over bedrock and glacial till. The present landscape was then gradually revealed as water levels fell during the next 1000 yr (Anderson and Lewis 1985; Naldrett 1991; Gilbert and Shaw 1992; Gilbert 1993).

By 11 400 yr BP (Fig. 1), the St. Lawrence valley was open. Isostatic depression to the northeast lowered the Lake Ontario outlet, then situated south of a sill at Greater Main Duck and Galloo Islands, to a level about 40 m below the present level, allowing incursion of the Champlain Sea to the Ontario Basin (Andrews 1970; Anderson and Lewis 1985; Fulton and Richard 1987; Gilbert 1993). All of the study area was exposed at this time. In the Kingston Basin, small lakes formed in depressions and a river system drained to the east on the newly exposed lake floor. Evidence of large wetlands along this river and lake system, similar to those of the present Cataraqui River, has been found at an elevation 15–20 m below the present-day Lake Ontario surface (Gilbert and Shaw 1992). Subsequent isostatic rebound and uplift of the St. Lawrence River caused lake levels to rise, flooding the coastal area again. The isolated lakes in the Kingston Basin

**Fig. 2.** (a) Stratigraphy and chronology of sediments on a north-south transect of the lagoon of the Cataraqui River, Kingston, Ont. Glaciolacustrine clay is overlain by marsh sediments, including gyttja and peat. Asterisks show depths at which samples analyzed for radiocarbon dating were collected. (b) Deposition of peats and gyttja in relation to lake levels, with two peat surfaces that were flooded. (c) Relationship between water levels and sediment surfaces during the last 4000 yr (from Dalrymple and Carey 1990).



**Fig. 3.** Annual differences from the long-term mean water level of the Kingston Basin since 1910: the St. Lawrence Seaway opened in 1957. The inset diagram shows the annual pattern of maximum, mean, and minimum monthly water levels. Levels are in metres above sea level.



gradually enlarged and merged with Lake Ontario, probably before 8000 yr BP (Gilbert and Shaw 1992). Water levels reached present or somewhat higher levels (within 2–3 m) by about 4000 yr BP. The last parts of the basin to be flooded were in the Bay of Quinte: Picton Bay was flooded by 6000 yr BP; while Sly (1986) indicates that the northern part of the bay, west of Telegraph Narrows, was not part of the main lake until after 2500 yr BP.

The age of present shore habitats therefore varies, with few exceeding 2000 yr, in comparison with the 10 000 yr history of some inland basins in the drainage area of the rivers entering the Kingston Basin (Terasmae 1968).

## Temporal changes in habitat components in the Kingston Basin

### Physical components

#### (A) Water levels

Isostatic tilting is still occurring in Lake Ontario. The eastern outlet of Lake Ontario is rising with respect to the western end at a rate of about  $1.8 \text{ mm}\cdot\text{yr}^{-1}$  (Clark and Persoage 1970; Sly and Prior 1984; Anderson and Lewis 1985). This movement is sufficiently slow for wetlands and their plants to remain in equilibrium with it. Superimposed on this long-term change are shorter term events including the following:

- (1) seiches and storms, with an amplitude of centimetres or decimetres, lasting a few days (Dalrymple and Price 1993);
- (2) seasonal changes (Fig. 3) generally varying by about 0.5 m in 6 months (Price 1994);
- (3) interannual and decadal differences of up to 1 m, resulting

from the changing balance of precipitation and evapotranspiration (Bishop 1987) (Fig. 3); and

- (4) long-term oscillations of 0.5–1 m with periods of the order of 200–300 yr, presumably due to climate changes (Dalrymple and Carey 1990).

Fractal analysis of the historical record of mean annual water levels in Lake Ontario (Fig. 3) indicates that water levels vary continuously at all temporal scales, so that it is inappropriate to speak of discrete periods or cycles. Lake Ontario wetlands are described as “pulse stabilized” rather than cyclic (cf. IJC Functional Group 2 1989; Planck 1993; Wilcox 1993).

Important questions for managers are whether global warming is occurring (Pocklington 1994) and, if so, what effects it could have on water levels in the Great Lakes region. Current models vary in assessing the balance between precipitation and evaporation, with resulting predictions ranging from a drop of 1.5 m to a rise of the same magnitude (Rogers and Harshdeep 1994).

The effects of level changes that have occurred in the past are exemplified by observations in the estuarine part of the Cataraqui River (Fig. 2). Two periods of flooding followed by lower water levels are shown in the sediment record, with high water coinciding with warm periods (Dalrymple and Carey 1990; Dalrymple and Price 1994). The marsh responded to this stress in two ways: (i) sediment and vegetation changed gradually over most of the period, but (ii) two sharp thresholds occurred when a peat mat was flooded. At these thresholds the wetland appears to have changed abruptly from an emergent marsh, accumulating peat, to an open-water lagoon with submerged plants, accumulating gyttja. Thus, the ecosystem continued to function, but differently, showing the type of response to stress in the fourth category distinguished by Keith

(1994). These events in the sedimentary history are probably similar to modern flooding events described by Jaworski et al. (1979) and Quinlan and Mulamoottil (1987).

Is the present water-level regime of this region affected by the St. Lawrence Seaway? Water levels for the years 1912–1993 were compared for Lakes Ontario and Erie, and it was evident that Lake Ontario is subject to larger changes of level than Lake Erie and that the curves for the two lakes diverged in the late 1960s. Annual differences from the long-term mean for Lake Ontario (Fig. 3) indicate that the lake was lower than normal at the time of the St. Lawrence Seaway opening in 1957. Comparing the periods 1912–1956 and 1969–1993, we found a lowering from the predicted mean in the later period. Since 1968, Lake Ontario has been consistently lower than its long-term mean by about 0.3 m. Therefore, the Seaway can be expected to have caused habitat changes, allowing woody growth, cattail marshes, and submerged plant beds to shift downslope.

The current regulation plan of Lake Ontario is designed to keep lake levels within a range of 1.2 m; in reality they vary with a range of approximately 2 m (IJC Levels Reference Study Board 1993).

#### (B) Sedimentation

Changes in rates or types of sedimentation are important in nearshore habitats because different fish communities are associated with different sediment types, and because turbidity and rapid sedimentation can damage some organisms. The associations of fish with different sediment types such as wood debris, gyttja, sand, etc. have been described by Keast et al. (1978), Keast (1984), Stephenson (1990), Jude and Pappas (1992), and Eadie and Keast (1994). If as cores from the Cataraqui River (Fig. 2), Deadman Bay, and other sites show (Johnston 1972; Dalrymple and Carey 1990) local habitats have undergone sudden alterations of sediment type in the past, their associated fish communities are likely to have changed too. As an example of such change, rapid sedimentation of dead *Cladophora* and *Myriophyllum* was reported to prevent lake trout (*Salvelinus namaycush*) from spawning successfully, by covering some spawning beds in the Kingston Basin during the 1960s (Sly 1991).

Events such as storms can significantly change the rate of sedimentation. Lacking evidence from the study area, a well-documented case can be cited from New York State when a 1972 hurricane caused 17 cm of rain to fall in 24 h. In Lake Canandaigua, light transparency decreased rapidly (Secchi disc readings fell from 3.5 to 0.5 m in 12 h) because of riverine input, returning to prestorm values in about a month. In Lake Canandaigua the algal community changed, and in Lake Cayuga the macrophyte community lost biomass and became dominated by *Myriophyllum* (Oglesby and Vogel 1976; Eaton and Kardos 1978). Presumably, storm events and subsequent changes in sediment loads can similarly affect the nearshore of Lake Ontario.

Sediments along the shoreline of the Bay of Quinte show high spatial patchiness (Dushenko 1990). Samples from 0.5–m water depth all contained some fine sand and some organic content; in addition, 79% had coarse sand, 77% silt, 39% gravel, and 20% clay. In cattail marshes, substrate patchiness is also high, with the organic content ranging from 38 to 76% (Greig 1989). Such patchiness also occurs in older sedi-

ments; in 12 cores collected within Deadman Bay (Johnston 1972) the number of layers with shells ranged from 0 to 10 and the number of layers with wood fragments ranged from 0 to 3. These data illustrate the heterolithic nature of shallow water environments, creating habitat changes for their biota as sedimentation regimes alter.

From the managerial point of view the effects of development on sediment type are notable. Johnston (1972) in Deadman Bay, Frappe (1979) in the Cataraqui River, and McLaughlin (1993) in the Bay of Quinte have all noted differences in sediment type associated with runoff from developments. These include cottages, condominiums, industrial plants, and marinas.

Marl, an unconsolidated sediment composed of calcium carbonate (calcite), occurs in layers in postglacial organic sediments from lakes, wetlands, and stream valleys, inland from the Lake Ontario shore between Belleville and Kingston (Guillet 1969; Vreeken 1981, 1994). Long-term rates of marl accumulation inland have ranged from 0.03 to 0.47 cm·yr<sup>-1</sup>. Lake “whiting” events (visible precipitation of marl) are now being observed in Lake Ontario on an increasingly frequent and large scale. In the last 50 yr, calcite in sediments in the Niagara basin has increased by an order of magnitude, and in the Rochester Basin, calcite precipitation began about 1920 (Schelske et al. 1988). In the Kingston Basin, calcium carbonate was precipitated near Wolfe Island in at least 5 of the 7 yr between 1977 and 1983 (Sylvestre et al. 1987). The cause is generally considered to be uptake of CO<sub>2</sub> by algae, causing pH to rise, so that the epilimnion becomes supersaturated with calcium and carbonate resulting in precipitation. Marl in a core from the Bateau Channel is considered to be similar in origin (Gilbert 1990).

Impacts of whittings on organisms in the nearshore zone are not known. Marl deposits on macrophytes in the study area vary within the summer and between years (Crowder et al. 1977; Crowder and Bristow 1986), presumably because water temperatures fluctuate (Gilbert and Leask 1981). Marl deposition increases during eutrophication and has been suggested as a factor causing declines of macrophytes (De Nie 1987).

## Chemical components

#### (C) Acidity

Discussions of increasing acidity due to acid precipitation have generally excluded Lake Ontario because it is well buffered (Charles 1991). In surface sediments in the Bay of Quinte, however, the pH ranges from 9.3 to 5.5 (Dushenko 1990) and in Quinte cattail marshes water pH ranges from 7.6 to 5.5 (A.A. Crowder, unpublished data). Acid precipitation or drainage has maximal effect in marshes with limited lake influence. Potential for acid shock in spring runoff was discussed by Sly (1991). Because niches of many coastal and wetland organisms are sharply defined by their pH tolerance, further acidification of marsh or shoreline habitats could result in community changes. Amphibian eggs, for example, are sensitive to increased acidity (Scheuhammer 1991). The rate at which acidity causes community change can be rapid; for example, algal communities can change within a season (Charles 1991).

*(D) Salinity*

Sodium chloride is an example of an inorganic industrial compound added to the Great Lakes in the last two centuries. Until about 1910, salt concentrations in Lake Ontario were steady at approximately 8 ppm. They then began to increase by approximately 4% per decade, with the rate slowing to 3% per decade in the last 30 yr (Beeton 1965; Johnston 1972; Pringle et al. 1981; Sly 1991). Creeks in the Kingston Basin show high concentrations of chloride in spring; road salt is considered to be the source (Ralston and Hamilton 1978; Crowder and McLaughlin 1993a; Stride 1993).

Salt-tolerant species are among the exotics that have invaded Lake Ontario (Mills et al. 1993). They include algae, invertebrates, fish, and macrophytes. The macrophyte community in the Bay of Quinte has become less diverse in the last half century; when the growth of common plant species from the Bay was tested in a range of salt solutions, the most halophilic species was *Myriophyllum spicatum*, which dominated the Bay during its most eutrophic period (Crowder and Bristow 1986; McLaughlin 1993). The present dominant, *Vallisneria americana*, is also salt-tolerant (Korschgen and Green 1987).

*(E) Nutrient status*

Eutrophication has been documented in the Kingston Basin most thoroughly for the Bay of Quinte (Minns et al. 1986; Bay of Quinte RAP Committee 1990). Historic episodes of enrichment by phosphorus are recorded by sediment and fossil changes in the Bay, and a major enrichment phase began in the 1930s, culminating in hypereutrophication and followed by control of point-source phosphorus inputs after 1978. Because of control, offshore P concentration during the ice-free season has now been lowered to a mean of 37  $\mu\text{g}\cdot\text{L}^{-1}$  (Bay Of Quinte RAP Committee 1990).

Nearshore sites have not necessarily followed the lakewide pattern of a decrease in eutrophication since the 1970s, if they are affected by local sewage inputs or land drainage. Examples of local areas currently experiencing eutrophication include the lower Napanee River, Hay Bay, Landon Bay, Collin's Bay, and the Little Cataraqui River (Bay of Quinte RAP Committee 1990; Browne 1991).

*(F) Contamination*

Loading of metals and organic compounds in Lake Ontario has recently been reviewed by Allan and Ball (1990). Loading of both increased until the early 1970s and has since been decreasing. This trend is shown by data from the Moira River (Fig. 4) for metals and phenolics.

In the nearshore, local sources of contamination are important. Metals have been derived from local industries, largely situated on the main river valleys; from waste dumps; and from mining and smelting. Mining began in the Moira Valley in the mid-19th century and has left a legacy of tailings, which are now treated to precipitate arsenic (Johnston 1978; Mudroch and Capobianco 1980; Paehlke et al. 1982; Crowder 1994). To prevent contamination of the Moira River this treatment will have to continue indefinitely. In 1990 the influence of the mines was still apparent in elevated concentrations of Cr, Cu, Ni, and Co in shoreline sediments, attenuating with distance away from the mouth of the Moira River (Dushenko 1990). Metals currently exceeding provincial guidelines for

aquatic life in the Bay of Quinte include Cr, Hg, Mn, Fe, Cu, Pb, Zn, and the metalloid As (Poulton 1992).

Organic compounds, which peaked in loading during the 1970s, included herbicides and pesticides. Substances causing concern in the Kingston Basin at present include phenols and pentachlorophenol (Bay of Quinte RAP Committee 1990). Substances commonly reported in local analyses include trichlorobenzenes and hexachlorobutadiene, hexachlorobenzene, DDE, and DDT (Poulton 1992).

Habitats contaminated by organics include river mouths and wetlands near waste dumps; that is, sites with local terrestrial inputs. Examples include the Trent and Cataraqui rivers and Picton Marsh Creek. Some nearshore sites have sediments contaminated by both metals and organic compounds (Johnston 1978; Frape 1979; Creasy 1981; Minns et al. 1986; Bay of Quinte RAP Committee 1990).

**Biotic components***(G) Algae*

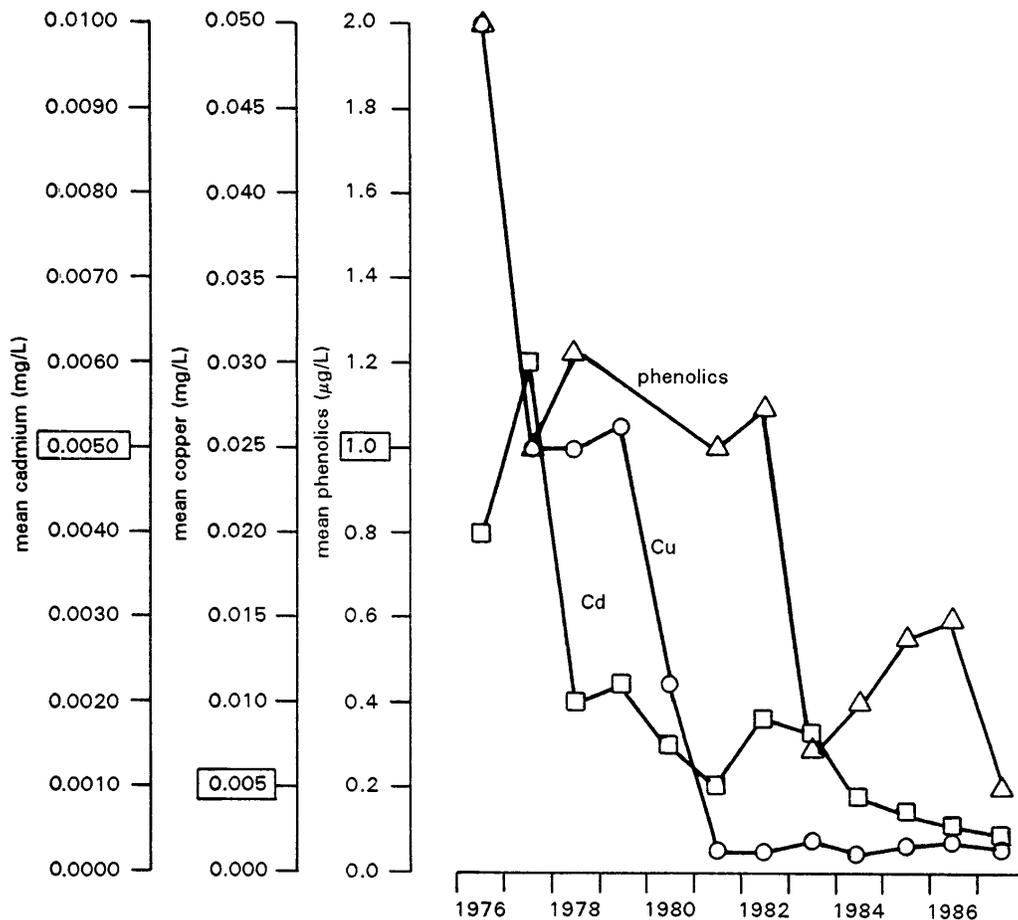
Changes in the algal community of Lake Ontario have been shown by microfossils, mainly diatoms and chrysophytes, extracted from sediment cores (Schelske et al. 1988; Schelske 1991; Stoermer 1993). Deductions about historic or prehistoric lake conditions can be made by statistical comparisons of dated microfossil assemblages with algal assemblages from present-day lakes; "calibration sets" of present-day lakes for such comparisons have been selected to show gradients of water chemistry and physical conditions. Such gradients include acidity, salinity, P content, and temperature, because the specific niches of algae are differentiated by such factors (Charles 1991).

In Lake Ontario, algal assemblages have shown little stability since the 18th century. Since 1770, at least 11 separate algal zones can be distinguished, using cluster analysis of the most abundant diatom taxa (Stoermer et al. 1985). Five phases are generally recognized in the diatom assemblages:

- (1) a fairly steady state prior to 1770, with P as the limiting element;
- (2) increased diatom accumulation with increased anthropogenic nutrient loading;
- (3) decreased diatom accumulation, with silica the limiting element during summer stratification;
- (4) further decrease with silica limitation during periods of lake circulation; and
- (5) increased diatom accumulation with reductions in phosphorus loading since the 1970s.

Diatom assemblages in the lake can show rapid changes. Sly (1991) pointed out that in the Bay of Quinte an oligotrophic assemblage in 1835 had changed to a eutrophic one by 1852; during that period lumbering, farming, and industry were rapidly changing water chemistry, amount and temperature of runoff, turbidity, and rates of sedimentation (Warwick 1980; Sly 1991). The group of algae considered most sensitive to such changes are not diatoms, but chrysophytes; Lake Ontario sediments show a rapid decline in chrysophyte numbers during the period 1831–1847 (Stoermer 1993). The declines of diatoms and chrysophytes have not been indicative of overall lowered algal productivity as eutrophic conditions have gen-

**Fig. 4.** Mean annual concentrations of cadmium, copper, and phenolic compounds in the lower Moira River from 1976 to 1988. Boxes indicate the Ontario water quality objectives for protection of aquatic life. Data are from Beak Consultants (1988).



erally allowed increases in biomass and productivity of blue-green and filamentous green algae (Bay of Quinte RAP Committee 1990; Minns et al. 1986).

The general trends in algal communities of Lake Ontario described above have been based on samples taken from open water areas; trends in nearshore or wetland algal communities can be different, because inshore nutrient supplies may be increased by pulses of riverine loading (Stoermer 1993). An example of opposite trends in the open lake and an inshore site is provided by algae in Hamilton Harbour – Coote's Paradise (Yang et al. 1993) since the 1970s. While diatom numbers in open water have been increasing during this period, diatoms have decreased in numbers and diversity in this inshore habitat. The number of diatom species before the year 1800 was 28–37, which increased to a maximum of 55 about 1900, and declined to 23 by 1986. Rapid change after 1970 has been attributed to turbidity, eutrophication, and contamination (Yang et al. 1993).

The Kingston Basin has not lost species in this drastic way. Following extreme eutrophication and point-source P control in the Bay of Quinte about 300 phytoplankton species now occur, with diatoms predominating in early summer, followed in late summer by blue-greens. Control of point-source P has decreased offshore algal biomass but has not altered the dominant species.

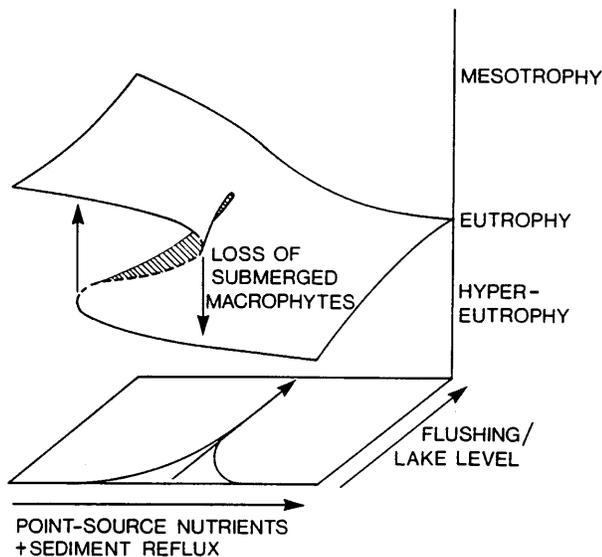
Inshore, *Cladophora* blooms were abundant in the Kingston Basin, and in the Bay of Quinte during the 1960s and 1970s before control of point-source P, but these subsequently declined (Painter and Kamaitis 1985). Quantitative data are not available on current inshore algal communities in the Kingston Basin, although algal blooms are frequently observed in bays and marshes (Browne 1991; McLaughlin 1993).

For a manager of fish habitat the importance of frequent or major changes in algal communities, such as those described above, lies in structural impacts (e.g., those due to *Cladophora*), in changes in light penetration affecting submerged plant growth and fish behaviour (e.g., during blue-green blooms), and in changes in availability of specific food items for invertebrates.

#### (H) Macrophytes

Eutrophication first causes increases in biomass of algae and macrophytes, causing fouling of fish nets and propellers. A scenario follows, described for many sites in Europe and the eastern seaboard of the United States (De Nie 1987; Carter and Rybicki 1985, 1986), in which the macrophytes decrease in biomass and become confined to shallow areas. The decline is due primarily to shading, as turbidity increases because of plankton, dead material, and inorganic particles. The change

**Fig. 5.** A catastrophe model for change in submerged habitats in the Bay of Quinte (after Minns et al. 1986). Point-source nutrients and sediment reflux caused an increase in the density of algae, which resulted in shading of submerged macrophytes. At this hypereutrophic state, macrophyte beds died off rapidly. Suspended sediment has slowed recovery of the macrophytes although point-source phosphorus loads have been decreased.



in area of macrophyte beds can occur rapidly; for example, they may shrink by 25% of their area per year as deeper sites become turbid (De Nie 1987). A predictive equation for turbidity (measured as Secchi disc depth) was developed from data from Organization for Economic Co-operation and Development lakes, showing that increased loading of dissolved phosphorus results in increased concentration of chlorophyll *a*; the greater algal density decreases light penetration, causing Secchi disc readings to decrease (Vollenweider and Kerekes 1982).

In the Kingston Basin, there is anecdotal evidence of an increase in biomass of macrophytes during the 1960s, in the Bay of Quinte, coinciding with an increase in *Cladophora* (Crowder and Bristow 1986; Painter and Kamaitis 1985). During the 1970s the area of macrophyte beds and the biomass of macrophytes were extremely low (Crowder and Bristow 1986), coinciding with Secchi disc measurements less than 1.5 m.

Decline in area, biomass, and species richness of macrophytes in the Bay of Quinte during eutrophication was fitted to a catastrophe model (Minns et al. 1986). Once the decline of macrophytes had reached a critical value the ecosystem changed, functioning at a lower level (Fig. 5). Loss of fish habitat was part of the temporal change. Recently, some other areas in the Kingston Basin have had high turbidity and low biomass of submerged macrophytes because of local eutrophication (Browne 1991).

After P loading has been limited, greater water clarity and increased submerged macrophyte biomass and area have been reported in numerous European lakes (Sas 1989). Control of point-source P in the Bay of Quinte since 1978 has resulted in decreased algal biomass and a 0.2-m increase in mean Secchi disc measurements in open water (Bay of Quinte RAP Com-

mittee 1990). Inshore zones responded more slowly; light penetration had not increased by 1990, mainly because of the presence of seston in early summer and plankton in late summer (Dushenko 1990). By 1993, however, with improved light penetration, submerged macrophyte beds had increased in area and in biomass (Crowder and McLaughlin 1993b). The first colonists in deep areas were frequently charophytes (Revill Associates 1988; Dushenko et al. 1990; Crowder and McLaughlin 1993b). Light conditions appear to be changing rapidly in the mid-1990s because of zebra mussels (*Dreissena polymorpha*) (see Section L).

Introduced carp (*Cyprinus carpio*) ingest macrophytes and stir up sediment (De Nie 1987; Painter et al. 1988). Resuspension of sediment particles by carp is considered largely responsible for absence of submerged macrophytes in Hamilton Harbour – Coote's Paradise in western Lake Ontario (Painter et al. 1988). After experimental removal of carp, macrophytes can recolonize an area within weeks if propagules are present (Netherlands Ministry of Transport 1989). Carp are abundant in the Kingston Basin (O'Dacre 1992) and are known to ingest macrophytes in the Bay of Quinte (Powles et al. 1983). They could affect the structure of habitats, particularly in sheltered lagoons.

The areas of some emergent marshes in the basin have increased, but only descriptive data record this increase (Crowder and Bristow 1986). The drop in water levels since the construction of the St. Lawrence Seaway (a long-term drop of approximately 0.3 m in mean level, see Section B) should have allowed emergent marsh plants to move offshore and woody zones to shift downslope slightly (cf. Fig. 3). Although the long-term mean has been changed, fluctuations about the mean are sufficient to prevent marsh zones becoming static.

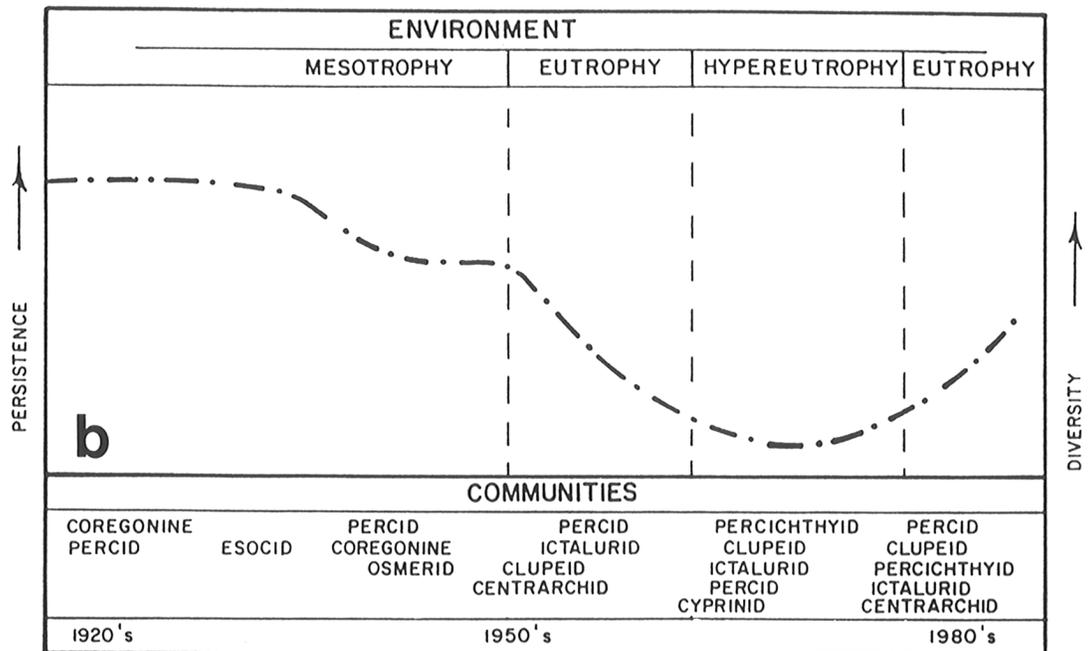
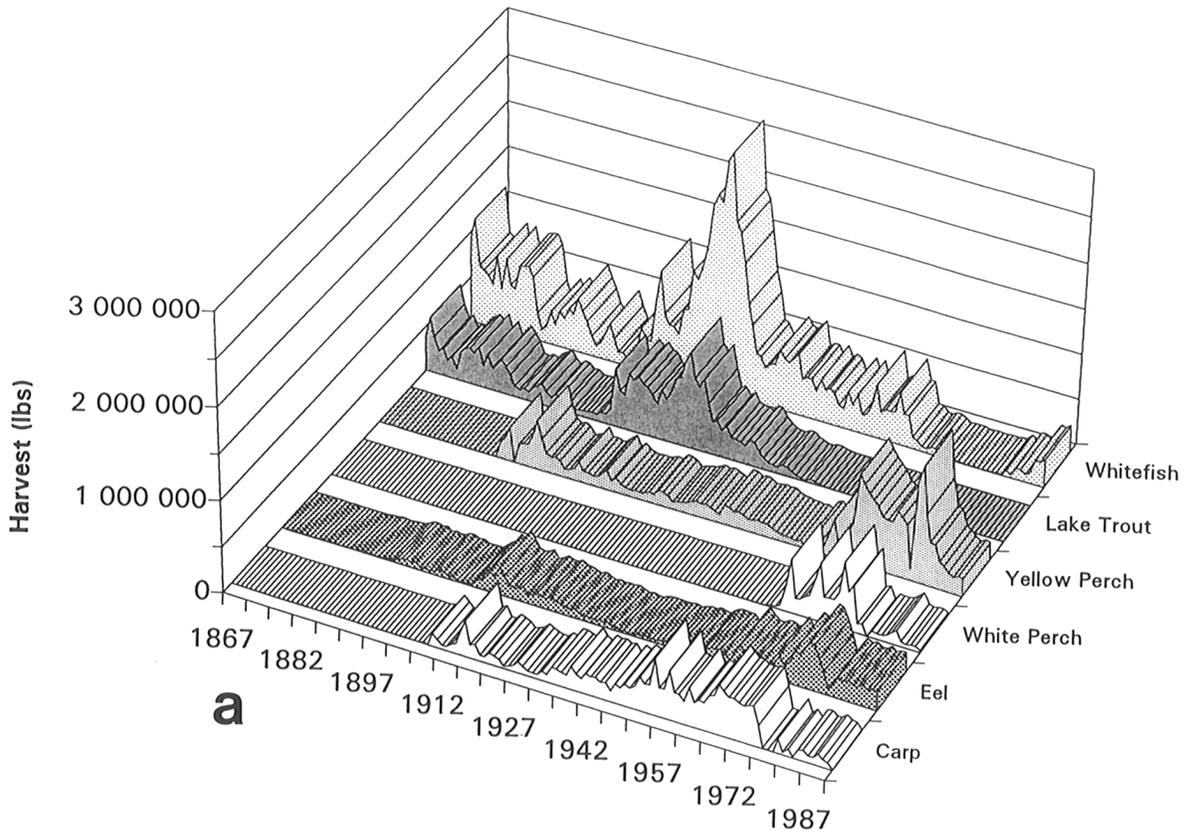
#### (1) Fish

Marked changes in the fish community of Lake Ontario have occurred in the last century (Christie 1973; Hurley 1986; Sly 1991). If harvest quantities can be assumed to reflect relative abundance of species, some of these changes, such as decreased abundance of lake whitefish (*Coregonus clupeaformis*) and lake trout, are shown in Fig. 6. Changes in the population size of less abundant species, such as lake sturgeon (*Acipenser fulvescens*), are not shown.

Four possible causes of these changes are listed below.

- (1) Changes of water temperature regimes. Deforestation is likely to have increased the temperature of stream waters in the region, beginning in the 1830s (Sly 1991). Warming trends may have diminished salmon spawning success, caused die-off of alewife (*Alosa pseudoharengus*), and increased spawning success of sea lamprey (*Petromyzon marinus*) (Sly 1991). In other periods, unusually cold winters are considered responsible for declines of warmwater fish such as white perch (*Morone americana*) (Christie 1973). Degraded coastal habitats, such as those affected by urbanization, are considered to favour warmwater species including white perch, common carp, suckers, and gizzard shad (*Dorosoma cepedianum*) (Holmes 1988). The present fish community of coastal waters has been described by Stephenson (1990) and by Jude and Pappas (1992) and contains several warmwater species.
- (2) Introductions of exotic species, including carp (about

**Fig. 6.** (a) Rapid changes in populations of six species of fish in Lake Ontario from 1867 to 1987, as shown by commercial harvests (in lbs.). Data from Ontario Ministry of Natural Resources, Napanee, Ont. (b) Changes in the fish community of the Kingston Basin during the period 1920–1990, showing a loss of dominance by coregonid fish. Diversity was lowest during the late 1960s (after Sly 1991). The temporal scale is that of Sly (1991).



1879), resulting in loss of macrophyte habitat (Jude and Pappas 1992).

- (3) Changes in water chemistry, including decreased oxygen in bottom waters during decay of dead algae and macrophytes during eutrophication. This has the effect of making bottom waters unusable by species such as lake trout.
- (4) Overfishing of piscivores, resulting in unbalanced and rapidly changing food webs (Minns et al. 1986, 1987).

The fish community of the Kingston Basin shows some of the responses to stress listed in the introduction. New features have been incorporated in the ecosystem, such as stocked salmonids, and the ecosystem functions differently from the way it did a century ago, with its main economic value now derived from walleye (*Stizostedion vitreum*). About 20 species of fish use shoreline habitats in Lake Ontario (Stephenson 1990; Jude and Pappas 1992) and their populations can be regarded as being unstable and unpredictable in occurrence.

#### (J) Amphibians and reptiles

Wetlands and coastal waters in the Kingston Basin are year-round habitats for snapping (*Chelydra serpentina*) and painted turtles (*Chrysemys picta*), salamanders, bullfrogs (*Rana catesbiana*), and green frogs (*Rana clamitans*). Anecdotal evidence of declining abundance of these taxa is widespread (Cook 1989; Bay of Quinte RAP Committee 1990; OMNR 1994b). Some of their early developmental stages, including eggs, are sensitive to metals such as aluminum and copper, especially under acid conditions (Freda 1991). A decrease in abundance of snapping turtles in the study region has been attributed to organic contaminants in their eggs; eggs of snapping turtles collected from the Bay of Quinte contained PCB, dioxin, furans, and dieldrin and showed a high proportion of dead or deformed embryos in comparison with uncontaminated eggs collected from a control site in Algonquin Park (Struger et al. 1993). In addition to food-chain effects, turtles alter habitat by grazing.

#### (K) Piscivorous birds

Colonies of some fish-eating birds in Lake Ontario, including common terns (*Sterna hirundo*), herring gulls (*Larus argentatus*), and double-crested cormorants (*Phalacrocorax auritus*), had decreasing numbers of birds in the 1960s. Reproductive failures were found to be caused by thin eggshells that were easily broken, embryos that died during incubation, and unusual incubation behaviour by adult birds (Swain 1981). A high proportion of chicks with deformities was also observed, including common terns with crossed bills, small eyes, and two pairs of feet (Gilbertson et al. 1989). Sites in the Kingston Basin where reproductive failures were monitored and where deaths and deformities were found to be correlated with organic contaminants in eggs of gulls and terns included Snake Island, Pigeon Island, and Little Galloo Island (Struger et al. 1987; Fox and Weseloh 1987; Weseloh et al. 1989; Gilbertson et al. 1989).

Since the late 1970s concentrations of contaminants in the birds' eggs have decreased, although not steadily (Gilbertson et al. 1989). In the eggs of herring gulls from Snake Island, dioxin (2,3,7,8-TCDD) concentration fell from 175 ppt in 1981 to 80 ppt in 1989 (Environment Canada 1991). By 1994, the content of PCB, dioxins, and DDE in herring gull eggs in

**Table 1.** The increasing rate of introductions of species to Lake Ontario (after Mills et al. 1993).

Time	No. of introduced species
1810–1839	1
1840–1869	15
1870–1896	26
1900–1929	22
1930–1959	33
1960–1990	41

the Great Lakes as a whole was reported to be 90% less than that measured in the late 1970s (Environment Canada 1994).

As contaminants in eggs have decreased, the reproductive success of gulls, terns, and cormorants has increased. Rates of recovery are better documented than declines for most of these species. The decline of double-crested cormorants had reduced them to about 125 pairs in the Great Lakes in 1971 but their estimated numbers are now up to about 35 000 pairs (Prince et al. 1992; Environment Canada 1994). The interest of population dynamics of birds for habitat managers is threefold: low bird populations may need protection; the amount of predation may be limiting fish populations; and dense bird populations affect nutrient cycling, for example by adding nitrogen to reefs or small islands.

#### (L) Introduction of exotic species

The rate of introduction of exotic species has increased rapidly during the last century and a half (Mills et al. 1993). The rate is summarized in Table 1 for three-decade intervals for the Great Lakes.

Population dynamics of introduced species vary greatly. Some successful introductions remain rare while others become abundant. Plant species such as eurasian milfoil (*Myriophyllum spicatum*) can take one or two decades to become dominant, remain so for a decade and then decline (Crowder and Bristow 1986, 1988). Carp, alewife, and sea lampreys are also thought to have increased in abundance slowly (Sly 1991). At the other extreme are zebra mussels and quagga mussels (*Dreissena bugensis*), first reported in Lake Erie in 1985 and in Lake Ontario in 1989 (Schaner and Stewart 1994). A single settled *Dreissena* and some veliger larvae were found in the Bay of Quinte in 1990 and "major colonies" were reported from the bay by 1993. Densities now exceed 100 000 individuals·m<sup>-2</sup> in the Trenton–Belleville area (Schaner and Stewart 1994). The mussels also occur at other sites in the Kingston Basin and in the St. Lawrence River.

Some introduced species have negligible effects on habitats while others greatly alter one or more of the physical, chemical, and biotic components. Invasive plants with strong impacts on habitats in the Kingston Basin include eurasian milfoil, frogbit (*Hydrocharis morsus-ranae*), and purple loosestrife (*Lythrum salicaria*) (White et al. 1993). They colonize submerged, floating-leaved, and emergent zones respectively.

Engel (1995) has summarized the impact of eurasian milfoil on fish habitats as follows:

"When dense, the plant obstructs swimming space of pelagic fishes, shelters too many juvenile fishes, and disrupts foraging movements of piscivores. In replacing native plants that harbor a diverse array of invertebrates, water milfoil cre-

ates food shortages for fishes. By blocking sunlight penetration and water movements, it depletes dissolved oxygen inshore that can cause fish kill when shoots decay in autumn.”

At present, zebra mussels have the greatest impact of any invasive animals. They have altered habitat structure by forming large colonies, have increased light penetration (Nicholls and Hopkins 1993), and presumably affect nutrient cycling. In Lake Erie, zebra mussels have caused major changes in food webs during the last decade, making the ecosystem “more benthic driven” (Haffner 1994).

## Discussion and implications for management

The preceding review of shoreline habitats in the Kingston Basin shows that the physical, chemical, and biotic components have all undergone significant change, at a variety of spatial and temporal scales. All such changes impose a stress of some magnitude on the ecosystem. Many of these changes are anthropogenic but others are natural, suggesting that, even in the absence of human interference, the shoreline environment is not “constant and continuing.” Therefore, given the existence of increasing financial constraints, the nature of the change must be analyzed carefully to determine whether management action is needed or possible.

Shoreline habitats in general are subject to more profound and rapid change than open lake settings. Shoreline areas are influenced by factors originating both from the lake as a whole (e.g., lake-level changes; lakewide water chemistry; introduction of exotic species) and from the surrounding land area (e.g., point-source contaminant loadings; sedimentation associated with construction activities). As a rule, stresses that originate from the adjacent land are likely to be more easily controlled by local management than those originating from the lake. Thus, it is useful to subdivide nearshore areas into those with greater or lesser amounts of terrestrial influence. For instance, wetlands in the estuarine reach of stream valleys are more susceptible to stresses from the land than wetlands within embayments without significant runoff. Similarly, the landward edge of a marsh is more likely to be adversely affected by terrestrial processes than the outer edge. It may then be more effective to devote local effort to those areas experiencing stress of terrestrial origin. Lakewide changes must be addressed in a different forum.

Of the many variables subject to change in nearshore habitats, physical factors (e.g., water-level changes; sedimentation and its influence on substrate character) and chemical factors (e.g., acidity, salinity, nutrient status, and contamination), together with the introduction of exotic species, are the primary external controls on the nature and behaviour of the ecosystem. Experience indicates, however, that changes in community structure brought about by a primary stress may trigger secondary changes in other components of the ecosystem, even though the other species are not seriously or even directly affected by the primary stress. Thus, cascade effects may occur because of the complex feedback relationships that exist between the various biotic components. For example, nutrient loading causing eutrophication in the Bay of Quinte led to increased turbidity, which then caused a decrease in macrophyte extent and biomass, accompanied by declines in the associated fauna. Managers need to consider these complex

interactions, both in assessing the likely influence of a particular development and in deciding which of the many changes affecting an ecosystem are most in need of attention. Stresses with the greatest likelihood of compounded effects require more urgent action than those which influence only minor and isolated components of an ecosystem.

The rates of change displayed by physical, chemical, and biotic components of nearshore habitats in the Kingston Basin span several orders of magnitude, from the very slow rise in water levels associated with isostatic uplift of the lake outlet, to the nearly instantaneous change in acidity (acid shock) experienced by local areas during spring runoff. In general, slow change is more likely to be tolerated by an ecosystem. Thus, sedimentary data from the Cataraqui River estuary indicate that the wetland has existed more or less continuously over the last 4000 years, despite gradually rising lake levels (Fig. 3). Changes that are truly cyclic, such as annual variations in water levels, are also likely to be accommodated by the ecosystem, as long as the change stays within usual limits.

By contrast, the most important stresses are not cyclic. Instead, they are events that exceed the tolerance of the ecosystem, such as extreme low or high water levels, heavy sedimentation caused by nearby development, the introduction of a new contaminant, or the invasion of a rapidly proliferating, exotic species. Of the five types of ecosystem response discussed by Keith (1994), all have occurred in the shoreline habitats of the Kingston Basin. Examples of each include (i) continued functioning but with hiccups (piscivorous birds in response to the increase and subsequent decrease of contaminants); (ii) continued functioning but at a lower level (fish stocks in response to overfishing, contaminants, and exotic species; Fig. 6); (iii) incorporation of new features (introduction of carp); (iv) functions differently (algal communities in response to changing nutrient status); and (v) collapse without regeneration (the two episodes of marsh loss seen in the sediments of the Cataraqui River estuary; Fig. 3).

Responses of type *v* are clearly of greatest concern. In general, they are more likely to be caused by rapid, large-magnitude changes, but may also result from relatively small changes if the ecosystem or one of its important biotic components is already near the limit of its tolerance to a particular stress. Prior to reaching this threshold, the existence of a stress may cause only slight or slow change, but once this threshold is exceeded, catastrophic change takes place. The dramatic decrease in macrophyte biomass referred to already is a case in point.

In summary, habitat managers should be aware that shoreline habitats of the Kingston Basin have experienced almost continuous change and will continue to experience change in response to natural events and human action. Not all changes can or should be subject to intervention. Stresses originating from nearby land areas are most amenable to intervention, whereas those of lakewide origin cannot be controlled locally. Management action should focus on those changes with the greatest likelihood of compounded effects or of exceeding the adaptation threshold of an ecosystem or an important component species.

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