American water lotus beds of Old Woman Creek estuary in 1888 (artist: Charles Courtney Curran).

CHAPTER 7. ECOLOGY

ESTUARY VEGETATION: MACROPHYTES

ADAPTATIONS FOR AQUATIC LIFE

The dominant plants in the estuary are hydrophytes—plants adapted to life in the water or in water-saturated soil. The larger (macroscopic) water plants are collectively known as macrophytes and encompass the vascular plants (those with well-developed conducting tissue such as aquatic mosses, liverworts, ferns, and flowering plants) as well as macroalgae. The evolution of vascular plants from simple marine forms involved increasing adaptations to terrestrial environments. Thus, hydrophytic vascular plants show a reversal in this trend by their development of specific adaptations to cope with re-invasion of aquatic environments (Arber 1920). Within the estuary exists a spectrum of plants ranging from those which are normally terrestrial, but which are able to endure occasional submergence, to those which are wholly adapted to an aquatic environment, having lost their capacity for a terrestrial existence.

Aquatic macrophytes, especially submerged forms, have adapted to reduced solar radiation as a consequence of the light-attenuating and filtering effects of water. Because water loss does not present a problem as it does with land plants, a dense cuticle is not required to prevent desiccation except for exposed surfaces of emergent or floating leaves. Aquatic plants are unusually porous, their tissues containing large intercellular spaces that are commonly arranged to form chambers (aerenchyma tissue). This arrangement enhances gas exchange and provides leaf buoyancy. Most hydrophytes obtain oxygen and carbon dioxide by direct diffusion between leaf tissues and the water. The large air channels then provide internal gas exchange pathways for stem and root tissues which are typically buried in anoxic muds. This mode of gas exchange is necessary in aquatic plants because unlike terrestrial soil, water-saturated soils and estuarine sediments are generally devoid of gaseous oxygen.

In addition to dim light and scarce oxygen, aquatic macrophytes must cope with vertical and horizontal motion of the water, an absence of transpiration, and inadequate nutrient-absorbing capacity of roots (Pieters 1901). For submerged plants the problem of obtaining adequate oxygen is exacerbated by the low solubility of oxygen in water (generally <10 mg/l) and a much slower rate of oxygen diffusion in water. Because water-saturated soils of coastal wetlands are generally anaerobic, hydrophytes have developed anatomical and morphological adaptations to compensate for soil oxygen deficiency, such as: (1) transport systems which supply oxygen to underground organs from aerial structures, (2) metabolic mechanisms which function under anoxic conditions and in the presence of toxic metabolic products, and (3) detoxifying mechanisms. Aquatic plants also differ from upland species in that they must absorb nitrogen as ammonium cations (NH_4^+) because denitrifying micro-organisms (present in anaerobic soils) scavenge nitrate anion (NO_3^-), the usual source of this nutrient (Etherington 1983).

Some vascular aquatic plants have so completely adapted themselves to a watery environment that they have dispensed with roots except in germinating seedlings. With the exception of *Ceratophyllum* (coontail) and *Wolffia* (water-meal), all the vascular plants of the estuary produce some roots. In *Lemna* and *Spirodela* (duckweeds), roots are short and slender organs used to position and stabilize the plant in the water. Rooted aquatic plants such as *Myriophyllum* (water milfoil) and *Potamogeton* (pondweeds) primarily utilize their roots both as an anchoring system and for nutrient uptake (Wetzel 2001).

Owing to their hollow center and reduced vascular bundles, the stems of most monocot submerged and emergent plants are well adapted to water movements—numerous, often large, cavities supply an abundance of oxygen to all parts of the plant. A central canal is present in *Potamogeton* (pondweeds) and in some dicots, as *Ceratophyllum* (coontail), which functions as the xylem vessel in land plants. For added support, the stem is strengthened by thickening of the cellulose tissue (collenchyma) at the angles of the cell walls.

REPRODUCTION IN AQUATIC PLANTS

Pollen produced by terrestrial plants is transferred from one flower to another by agents such as wind and insects. Pollination takes place in the same way for aquatic plants having aerial flowers; for those that live beneath the surface, reproduction presents special problems. Thus, many aquatic plants rely mainly on vegetative reproduction. Others emerge to flower and subsequently drop their seeds into the water, revealing their terrestrial evolutionary ancestry by achieving fertilization only in an air medium. Few aquatic plants are capable of fertilization underwater because most pollen is not resistant to water; *Ceratophyllum demersum* (coontail) is one of the rare plants fertilized underwater. Stamens are released at maturity from submerged flowers and rise to the surface where pollen is discharged and hopefully sinks onto a pistillate flower (Voss 1985). More commonly however, reproduction in *Ceratophyllum* is by simple fragmentation of the rather brittle stem.

Certain submerged plants, such as *Potamogeton nodosus* (knotty pondweed), produce some floating leaves which serve as a platform for the support of flowering spikes. In other cases where there are no floating leaves and the plant remains totally submerged, special structures have evolved to bring the flower to the surface. *Elodea canadensis* (common water-weed) has developed a long, thread-like flower stem (up to 15 cm long), arising from the axil of a leaf, which bears a small pink female flower. Rare male flowers are produced underwater, the buds of which float to the surface to liberate pollen which blows along the water to pollinate the female flowers. This sexual method of reproduction in *Elodea* is uncommon—usually this plant reproduces vegetatively by a portion of its stem breaking away to form a new plant (Brown 1971).

Vegetative reproduction is common in most aquatic plants and many produce special overwintering structures known as turions. Turions are specialized short stems on which the leaves are closely packed. In *Elodea*, the parent plant persists all winter, but the leaves at the tips of the stems form compact tution buds that do not separate until spring. *Potamogeton cripus* (curly pondweed) produces turions in the form of side shoots which break away from the parent and grow fresh roots and leaves (Brown 1971). *P. pectinatus* (sago pondweed) overwinters by means of tubers produced at the ends of special roots (Pieters 1901).

Most aquatic plants produce fewer seeds than land plants and in some, seed production is seldom if ever seen. Active vegetative propagation and the perennial character of water plants have tended to reduce the importance of seed production. Pieters (1901) reported that studies of the seeds of aquatic and wetland plants show that most seeds are heavier than water and do not float unless they are adhering in masses or have a surface not easily wetted. Some float, but only for a few days. Seeds of aquatic plants are not well adapted to being spread by animal agents. Thus, most aquatic seed distribution is thought to be local.

ZONATION OF ESTUARY PLANT COMMUNITIES

As with many protected embayments, the cove-like margins of Old Woman Creek Estuary show a great regularity in the distribution of aquatic plants. Such zonation was first described for European lakes a century ago (Magnin 1893, Arber 1920). Passing into the estuary from the shore, the following order is generally observed. First, there is a littoral zone of plants standing out of the water—*Phragmites* followed by *Scirpus* or *Sagittaria* and *Sparganium*; next, a belt of submersed plants consisting of *Potamogeton* and *Ceratophyllum*; and still farther from shore, a zone of plants with floating leaves, among which *Nelumbo lutea* is the dominant species (Whyte 1996).

Arber (1920) points out that one of the chief factors determining this zonation is that plants with floating leaves can only flourish if guarded from the wind. For this reason they generally do not occur at great distances from the shore, except in very sheltered basins such as the estuary of Old Woman Creek or among protective stands of emergent reeds (Pieters 1894). Typically, where the water is more exposed to prevailing winds and moderate wave action, broad-leaved plants are absent, their place being taken by *Myriophyllum*, whose highly divided leaves are uninjured by wave motion (Matthews 1914). As a rule, submersed plants form a zone farther from the shore than floating-leaved plants because the latter shades the lower layers of the water, reducing sunlight penetration to a level insufficient to support a deeper flora (Arber 1920). Because much of the estuary is sheltered, beds of *Nelumbo* are scattered throughout the open water (Figure 7.1); as a consequence, the most favorable habitat for submersed plants is limited to the intervening spaces.

Figure 7.1. Nelumbo *beds in Old Woman Creek estuary*
*(*Lotus Lilies*, a painting by Charles Courtney Curran in 1888; courtesy of Terra Museum of American Art).*

Zonation within Old Woman Creek estuary—the arrangement of taxa in aquatic and marsh plant communities to form a series of bands more or less parallel to the shoreline—is largely influenced by water depth and soil moisture. The slope, or gradient, of the shore and nearshore bottom controls the width of the bands; steep gradients yield narrow bands whereas gentle slopes produce wider bands. Typically four distinct zone of macrophytes are present in Lake Erie coastal embayments and marshes such as Old Woman Creek Estuary: Zone 1–submerged plants; Zone 2–rooted, floating–leaved plants; Zone 3–emergent plants; and Zone 4–wet shore plants.

Zone 1–Submerged Macrophytes

Plants in this zone grow in water up to several meters deep and colonize the bottom as long as water clarity permits sufficient sunlight to penetrate for effective photosynthesis. The generally turbid condition in the estuary limits the photic zone to a depth to 0.5 to 0.8 m (Herdendorf and Wilson 1987). The dominant submerged plants in the estuary are *Ceratophyllum demersum* (coontail) and *Potamogeton pectinatus* (sago pondweed). *Ceratophyllum* lives suspended in the water column, while *Potamogeton* is rooted to bottom (Figure 7.2). Except for the flowers, all parts of these plants are adapted to live under water. Stems are weak and the general structure of the plants is loose since water buoyancy reduces the requirement of the rigid support needed for plants living in an air environment. Stoma, the pores on the underside of leaves used for gas exchange in air, are also reduced or vestigial.

In response to reduced light illumination underwater, photosynthetic pigments (e.g. chlorophyll and carotenoids) are concentrated in surface (epidermal) tissue (Wetzel 1983). Submerged plants commonly have numerous and finely divided leaves and green (photosynthetic) stems to optimize the reduced light reaching them. These slender and threadlike leaves maximize surface area–to–volume ratios (thereby facilitating gas exchange) and minimize resistance to water currents. For example, *Ceratophyllum* leaves are split into many divisions, while *Potamogeton pectinatus* leaves are narrow and elongated. *Potomogeton pectinatus* also demonstrates a special adaptation for growth in turbid waters, such as that found in Old Woman Creek estuary. Mostly submerged, this aquatic plant has a crown of leaves on the upper portion of the stem that fan out near the water surface (Figure 7.3) to maximize exposure to available sunlight (Langlois 1954).

*Figure 7.2. Sago pondweed (*Potomogeton pectinatus*), a submerged plant rooted to the bottom (Charles E. Herdendorf).*

Also in this zone, *Elodea canadensis* (common waterweed) was first observed in the estuary in 1995 (Whyte 1996). Although this species was found in Old Woman Creek above the estuary in 1979, it has very limited distribution in both habitats. Thin leaves (e.g. two-cell thickness of *Elodea* leaves) make the most of dim light, but they also require adaptations to offset the turbulent motion of water. For example, ribs in broad leaves provide needed rigidity (Pieters 1901).

Another plant of this zone, the exotic *Myrophyllum spicatum* (Eurasian water milfoil), was first observed in the estuary in 1992 (Whyte 1996) but as of 2001 it has not firmly established a population in the estuary. Fragments of this invasive plant have been observed floating in the lower reaches of the estuary in each of the years after 1992, but apparently have been unable to root and form a viable reproducing population. Since all fragments have been observed near the estuary mouth, it appears that Lake Erie is the source of this exotic species.

Zone 2–Floating-Leaved Macrophytes

Floating-leaved plants are of two principal types, those attached to the bottom and those freely floating. Attached types are primarily flowering plants (angiosperms) that occur in water 0.5 to a few meters deep. Freely floating types are not rooted to the bottom and tend to accumulate in shallow, protected areas. Because of the generally turbid water and shallow depths of the estuary, zones 1 and 2 are often superimposed to form a single zone encompassing most of the open waters of the estuary. The dominant aquatic macrophytes in this zone are *Nelumbo lutea* (American water lotus), *Nymphaea odorata* (white water–lily, Figure 7.4), and to a lesser extent *Nuphar lutea advena*

Figure 7.3. Potomogeton pectinatus *(sago pondweed) showing crown of leaves on the upper portion of the stem that fan out near the water surface (Fassett 1957).*

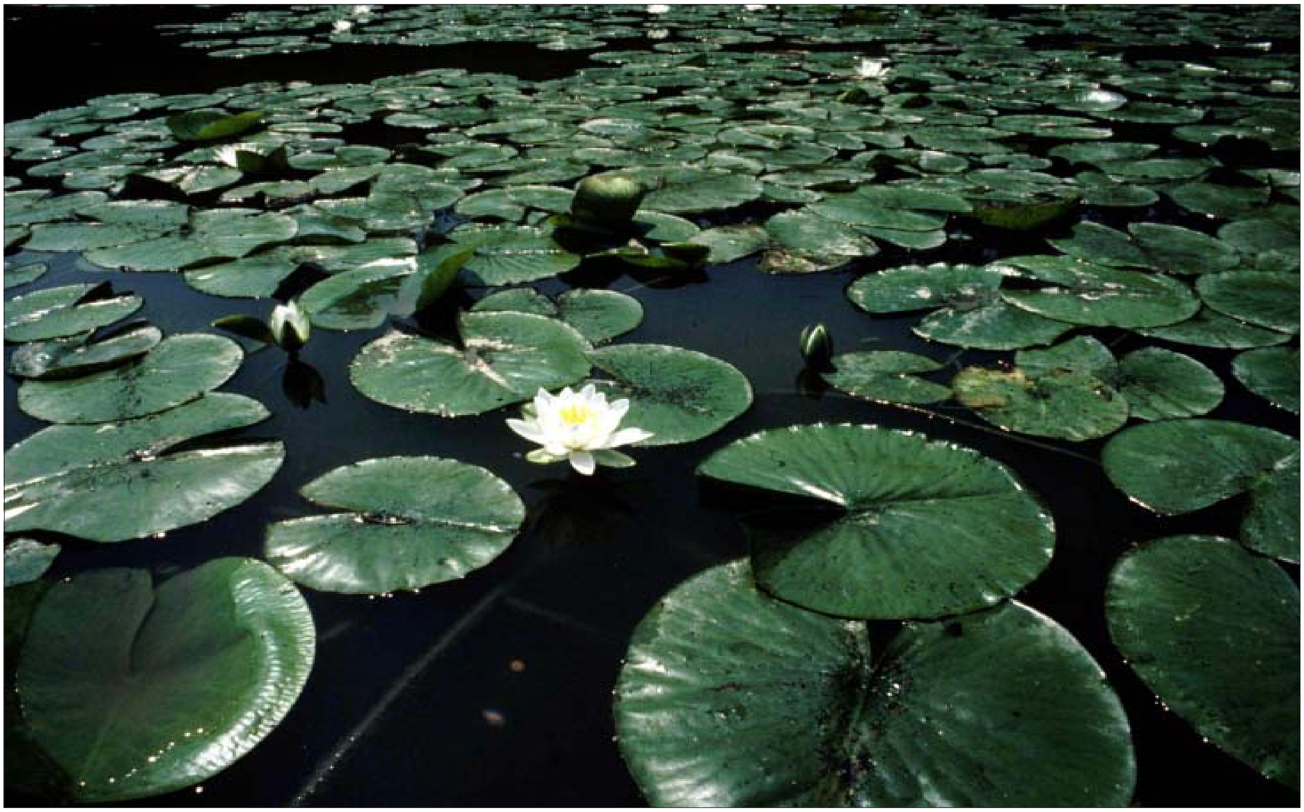


Figure 7.4. White water-lily *(*Nymphaea odorata*), a rooted, floating-leaved plant of the estuary (Gene Wright).*

(spatterdock). Floating *Lemna minor* (duckweed) often forms thick mats in the quiet waters among the lotus beds in early autumn (Figure 7.5).

The structure of floating leaves is strikingly different from that of submerged leaves in response to their dissimilar environments. The cells of the upper epidermis of the floating leaves are smaller, the cell walls are thicker, and more irregular in outline. Stomata are confined to the upper surface of the floating leaf, while they are virtually absent on the submerged leaf. Floating leaves are of finer texture than submerged ones and have a waxy covering to protect them from water injury. In *Nelumbo lutea* this protection is provided by numerous papillae (hairs), each arising from an epidermal cell. These fine projections hold a layer of air so that water falling on the leaf stands in large drops, as if on an oiled surface, until it can run off (Pieters 1901). *Nelumbo* is unique among the floating-leaved plants in the estuary in that it produces two distinct cohorts of leaves: the first are floating and emerge in late May while the second are aerial leaves that appear in late June or early July (Whyte 1996). The aerial leaves are generally above the range of seasonal water level fluctuations (Figure 7.1).

*Figure 7.5. Duckweed (*Lemna minor*) forms floating mats in protected coves of the estuary (Linda Feix).*

The boundary layer between air and water is a challenging environment for aquatic plants, where temperatures, water levels, current, and clarity vary from day to day as well as seasonally. The floating leaves of *Nuphar lutea advena* and *Nymphaea odorata* are well adapted to these conditions with long, bending stems (flexible petioles) that can alter their position in the water to keep the leaves on the surface. The leaves also have a waxy upper surface that resists wetting and desiccation. Gas exchange pores (stomata) are distributed on the upper surface instead of the lower as they are in terrestrial plants.

Zone 3–Emergent Macrophytes

Plants in this zone grow on water-saturated or shallowly submerged soils, i.e. water table 0.5 m below the soil surface to sediment covered by up to 1.5 m of water (Wetzel 1983). Most are perennial with rhizomes or corms embedded in the soil. In many species, morphologically different submerged or floating leaves precede mature aerial leaves. All produce aerial reproductive organs. Common plants of Old Woman Creek estuary in this zone include: *Leersia orzyoides* (rice cut-grass), *Phalaris arundinacea* (reed canary–grass), *Phragmites australis* (common reed), *Scirpus fluviatilis* (river bulrush), *Hibiscus moscheutos* (swamp rose-mallow, Figure 6.15), *Polygonum amphibium* (water smartweed. Figure 6.14), *Typha angustifolia* (narrow-leaved cattail, Figure 7.6), and various species of *Carex* (sedges).

Emergent monocotyledons, such as *Phragmites* and *Scirpus*, produce erect, linear leaves from an extensive anchoring system of rhizomes. Epidermal cells are elongated parallel to the long axis of the leaf, which allows flexibility for bending (Wetzel 1983). However, the cell walls are heavily thickened with cellulose, which provides the necessary rigidity. The internal tissue (mesophyll) is generally undifferentiated and contains large air spaces (lacunae). Emergent dicotyledons, such as *Hibiscus moscheutos* and *Polygonum amphibium* (water smartweed), produce erect, leafy stems which show greater anatomical differentiation. The internal tissue of the leaves is divided into typical upper palisade (elongated cells) layer and lower spongy (loosely packed cells) layer.

The roots and rhizomes of emergent macrophytes are permanently embedded in anaerobic sediment and are dependent on the aerial shoots for a supply of oxygen. Young, submerged foliage must be capable of respiring anaerobically until aerial growth is attained, since oxygen concentrations in water are very low in comparison to that in air. Once the foliage has emerged, the intercellular spaces increase in size, thus facilitating gaseous exchange between photosynthetic cells and the atmosphere. Rhizomes are capable of withstanding prolonged periods (up to a month) of low oxygen supply (Wetzel 1983).

*Figure 7.6. Narrow-leaved cattail (*Typha angustifolia*), an emergent plant that grows at the fringes of the estuary (Gene Wright).*

The emergent monocot *Sparganium* (bur-reed) demonstrates a variety of adaptations to match the different conditions experienced by various parts of the plant. Examination of successive cross-sections of the bur-reed shoot shows that the emergent leaf has a tough rigid structure with dense tissue that withstands the stress at the air-water interface. Farther down the shoot the tissue gets more spongy and full of air, an adaptation for supplying oxygen to the roots (Angel and Wolseley 1982).

Production of adventitious "water roots" close to a seasonally flooded surface is a common strategy for many water-tolerant species of the swamp forest. For example, *Salix alba* (white willow) forms a large tussock of such roots above the normal flood level. In woody plants such as *Salix* (willows) and *Nyssa sylvatica* (black gum), flooding first causes an overgrowth of lenticel tissue (hypertrophy) to form a callus from which adventitious roots then emerge close to the better oxygenated air-water interface. Some herbaceous plants behave similarly, for example the flood-tolerant *Epilobium glandulosum* (willow-herb) has hair-like roots for several cm above the stem base that produce adventitious surface roots on flooding.

Emergent plants of the estuary marshes, such as *Phragmites australis* (common reed), *Typha angustifolia* (narrow-leaved cattail), and *Scirpus fluviatilis* (river bulrush), grow in the most severe of all waterlogged environments, their roots and rhizomes in anaerobic mud and their leaves in a very exposed, often sunlit environment. Growth habits of monocotyledons make such plants well suited to this situation, particularly their free adventitous rooting and the frequent absence of stem tissue between the leaf and roots which facilitates the transport of oxygen (Etherington 1983).

Wetland plants of the estuary such as *Juncus effusus* (common rush), *Sagittaria latifolia* (arrowhead), *Scirpus validus* (soft-stem bulrush), *Sparganium eurycarpum* (bur-reed), *Typha latifolia* (broad-leaved cattail) are all well supplied with running rootstocks. Those of an association of *Scirpus* or *Typha* are particularly strong and wide spreading with each plant connected to all others of its species by thick rhizomes.

Zone 4–Wet Meadow and Floodplain Macrophytes

Lying adjacent to the shoreline of the estuary, this is a transition zone between estuarine and upland habitats (Figure 7.7). Plants in this zone grow in soil that is usually saturated with water to within a few centimeters of the surface. During wet periods the nearly flat to gently sloping terrain can be shallowly flooded and during droughts the water table can drop tens of centimeters below the surface. The plant community in this zone is represented by many monocots, including sedge genera such as *Carex*, *Cyperus*, *Eleocharis*, and *Scirpus*, rushes of the genus *Juncus*, and grasses of the genera *Calamagrostis*, *Cinna, Echinochloa*, *Glyceria*, *Leersia*, *Phalaris*, and *Phragmites* (Figure 2.12). Herbaceous dicots are represented by a wide variety of genera, including *Ranunculus* (buttercups and crowsfoots), *Polygonum* (smartweeds), *Rumex* (docks), *Lycopus* (water horehounds), *Asclepias* (milkweeds), *Verbena* (vervains), *Mentha* (mints), *Scutellaria* (skullcaps), *Mimulus* (monkey-flowers), *Galium* (bedstraws), and composite genera such as *Aster*, *Bidens* (beggarticks), *Eupatorium* (bonesets), and *Solidago* (goldenrods).

The wet floodplain adjacent to the south basin of the estuary also supports many woody plants and can aptly be termed a swamp forest. Typical woody genera include *Acer* (maples), *Carya* (walnuts), *Cephalanthus* (buttonbushes), *Cornus* (dogwoods), *Corylus* (hazelnuts), *Populus* (cottonwoods), *Quercus* (oaks), *Salix* (willows), *Tilia* (basswoods), and *Ulmus* (elms). Tree species such as these create a canopy that changes the character of wetlands from sunlit marshes with soft-stemmed plants to shady, woody swamps with relatively minor amounts of herbaceous biomass in the understory.

Like the emergent zone, wet meadows are highly productive in terms of biomass and fulfill effective water filtering functions. The juncture of the stems and roots for plants in this zone is typically just above the water table during the growing season. Thus, many of the species found in this zone must grow in a wetland and are termed obligate hydrophytes. However,

Figure 7.7. Wet meadow grasses fringe the mudflats of the estuary (Charles E. Herdendorf).

because of this zone's transition position between the estuary and the uplands, other species found in the zone have the ability to live in semi-dry situations and are termed facultative hydrophytes.

Trends In Macrophyte Populations

Great Lakes coastal wetlands are among the most dynamic wetland types. This dynamic nature is largely the result of the variable water levels in the five Great Lakes. The impact of seasonal and annual variations in water levels on the wetland vegetation can be significant. During high lake levels, as much as 50% of the emergent plant zones can become open water (Jaworski et al. 1979). Kelley et al. (1985) reported similar results from Pentwater Marsh, Michigan. Researchers have also reported this change in aquatic flora in Old Woman Creek (Klarer and Millie 1992, Whyte 1996, Whyte et al. 1997, Trexel-Kroll 2002).

The first detailed survey of the aquatic flora of Old Woman Creek estuary was conducted by John Marshall in 1974 (Marshall 1977, Marshall and Stuckey 1974). At that time, lake levels had risen to very high levels after a 15+year period of moderate to low levels (Figure 7.8). Lake levels remained elevated from 1974 through the spring of 1999, with record high levels recorded in 1985 and again in 1986. Marshall (1977) reported five distinct beds of emergent or floating-leaved species in the estuary in 1974. Dominant species included: *Peltandra virginica*, *Nelumbo lutea*, and *Polygonum amphibium*. Klarer and Millie (1992) examined the changes in macrophyte flora from 1974 through 1989. They prepared a map of the different regions of the estuary and a table recording the changes in flora from Marshall's original survey through 1989.

For this site profile, we have employed the same region map developed for the 1992 study (Figure 7.9) and a table from that study has been modified (Table 7.1) to incorporate the more recent floral studies of Whyte (1996), Whyte et al. (1997), Trexel-Kroll (2002) and Klarer (unpublished data). From 1977 through 1999 *Nelumbo lutea* dominated the macrophyte flora in Old Woman Creek estuary. In 1999 water levels declined to levels similar to those of the 1960s (Figure 7.8). With these declining water levels, the aquatic macrophyte community underwent a major shift in species composition. The dominant *Nelumbo*, the

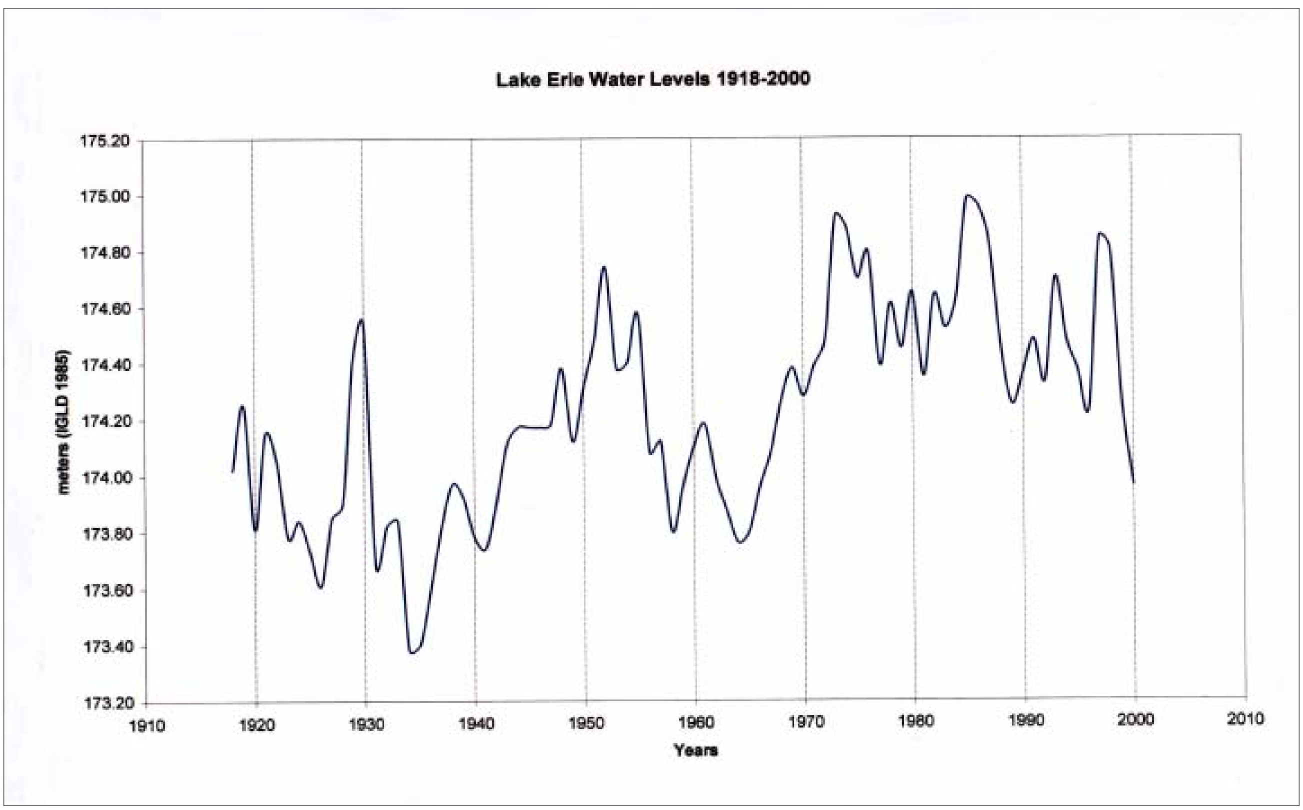


Figure 7.8. Mean annual Lake Erie water levels from 1918 to 2000 (NOAA).

TABLE 7.1. MACROPHYTE DOMINANCE BY AREAS OF THE OLD WOMAN CREEK ESTUARY FROM 1973 TO 2001

Site	1973	1984	1985	1986	1988	1989	1993	1994	1999	2000	2001
1	Peltandra virginica Potamogeton pectinatus Potamogeton nodosus Nymphaea odorata[1]	N. lutea P. pectinatus	N. lutea P. pectinatus	*	*	N. lutea P. pectinatus	N. lutea N. odorata Ceratophyllum demersum P. pectinatus	N. lutea N. odorata C. demersum P. pectinatus	N. lutea N. odorata C. demersum P. pectinatus	N. odorata Leersia oryzoides N. lutea Sagittaria latifolia	L. oryzoides Lemna minor S. latifolia N. odorata
2	Nelumbo lutea N. tuberosa P. pectinatus P. Nodosus	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea *Emergents	N. lutea *Emergents
3	Polygonum coccineum Hibiscus palustris Cornus drummondi	*	*	*	*	*	N. lutea	N. lutea	N. lutea	*Emergents N. lutea	*Emergents N. lutea
4	N. lutea Nuphar advena	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea *Emergents
5	P. coccineum N. advena	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea *Emergents	*Emergents	*Emergents
6	N. odorata	N. odorata	N. odorata	N. odorata	N. odorata	N. odorata	*	*	*Emergents	*Emergents	*Emergents
7	Peltandra virginica P. pectinatus	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea	N. lutea C. dermersum	N. lutea C. dermersum	N. lutea	*Emergents N. lutea	*Emergents N. lutea
8	*	N. lutea	N. lutea	*	*	*	N. lutea	N. lutea	N. lutea	*Emergents	*Emergents

NOTES:

Site locations are shown on Figure 7.9. If multiple species are listed for a particular site, they are given in descending order of abundance.

"*" denotes no vegetation reported.

"* Emergents" denotes undifferentiated emergent species including varying proportions of the following taxa: *Leersia oryzoides*, *Echinochloa* spp., *Phalaris arundinacea*, *Carex* spp., *Scirpus validus*, *Typha* spp., *Sparganium eurycarpum*, and *Sagitaria latafolia*.

1 *Nymphaea odorata* is the new name of *Nymphaea tuberosa* as recorded by Marshall (1976), Klarer and Millie (1992), and Whyte (1996)

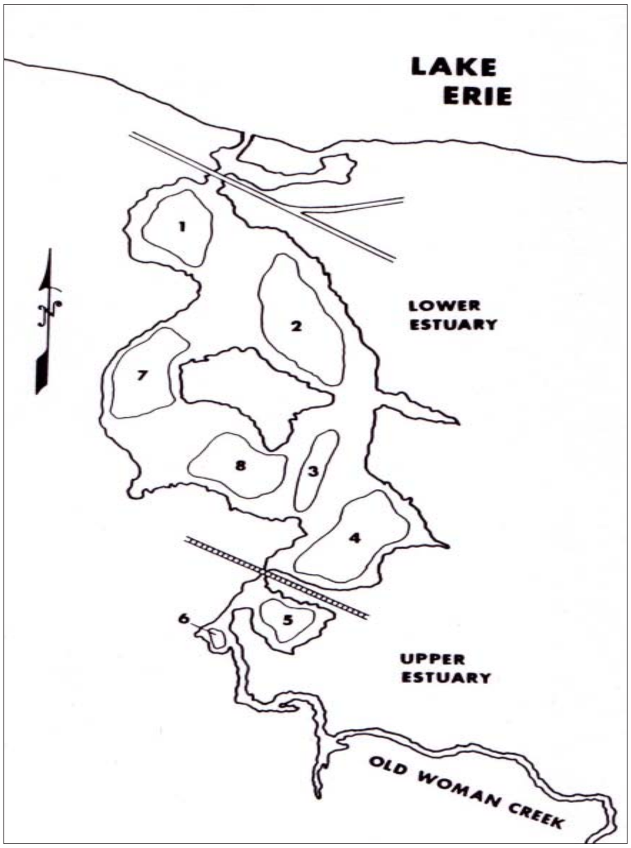


Figure 7.9. Old Woman Creek estuary map showing site locations of aquatic macrophyte beds and numbering system (Klarer and Millie 1992).

major species in the estuary from the late 1970s through 1999 (Figures 7.10 to 7.12), was replaced by emergent species in both 2000 and 2001 (Trexel-Kroll, 2002). Total vegetation cover rose from 40% in 1999 to greater than 70% in 2000 and 2001. The percent cover of emergent plants in the estuary rose from less than 10% in 1999 to greater than 45% in 2000 and even slightly greater in 2001. Although the areal extent of the vegetation did not markedly change between 2000 and 2001, there were noticeable changes in the species composition. The relative importance of floating-leaved species declined while duckweeds, submergents, and particularly emergent species increased. In the northwest embayment during 2001, the emergents were nearly equally divided between grasses—*Leersia*, *Echinochloa*, *Phragmites* (35% of total vegetation) and non-grasses—*Polygonum*, *Typha*, *Sparganium*, *Sagittaria* (42% of total vegetation), while in the major beds south and west of the island, the grasses—particularly *Leersia* and *Echinochloa*—accounted for 55% of the vegetation and the non-grasses only 22%.

During the period of *Nelumbo* dominance, this species demonstrated two distinct growth patterns: a general expansion in coverage in the estuary and a cyclic pattern of expansion and contraction within individual beds (Whyte et al. 1997). Over this 20+ year period, the percentage of *Nelumbo* cover ranged from 5.2% (1977) up to 35.6% (1993) coverage (Table 7.2). This cyclic expansion and contraction in an individual bed is readily apparent when examining the yearly *Nelumbo* distribution maps in Whyte et al (1997) (Figure 7.10). The major *Nelumbo* bed due north of the island expanded from 1977 to 1984, when it broke into two separate beds. The northern portion of the bed continued to migrate northwest in the estuary toward the mouth, from 1984 through 1989, while the southern part of the bed gradually disappeared.

TABLE 7.2. PERCENTAGE COVER OF *NELUMBO LUTEA* IN ESTUARY

Year	Percent Coverage
1977	5.2
1978	5.4
1979	12.8
1984	21.5
1985	16.6
1986	17.8
1988	20.3
1989	10.9
1993	35.6
1994	34.3
1995	34 (estimated)
1998	29.0
1999	30.4
2000	22 (estimated)
2001	20 (estimated)

Data Sources: Whyte 1999 and Klarer, unpublished

In summary, the aquatic macrophyte communities in Old Woman Creek estuary are very dynamic. The size and locations of the different beds change each year. During high water years (1980-1999) the vascular flora was dominated by *Nelumbo lutea*, while the emergent vegetation was largely confined to the shoreline edges of the estuary. When Lake Erie water levels dropped in 1999, many of the mudflat areas that had been underwater from 1980 through 1999 were exposed during the spring of 2000. These areas were quickly colonized by emergent vegetation.

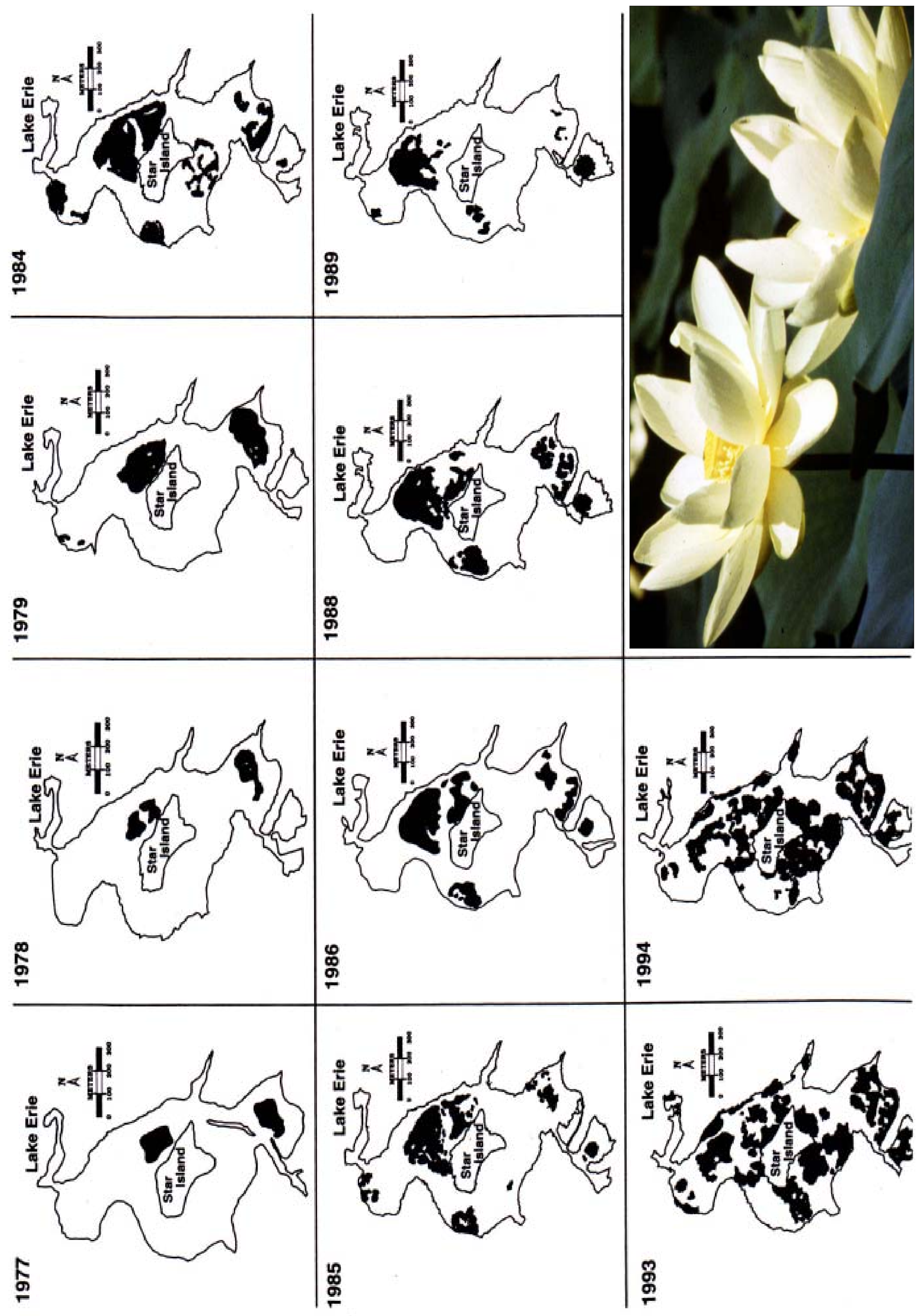


Figure 7.10. Distribution of Nelumbo lutea *in Old Woman Creek estuary from 1977 to 1994 (Whyte et al. 1997).*

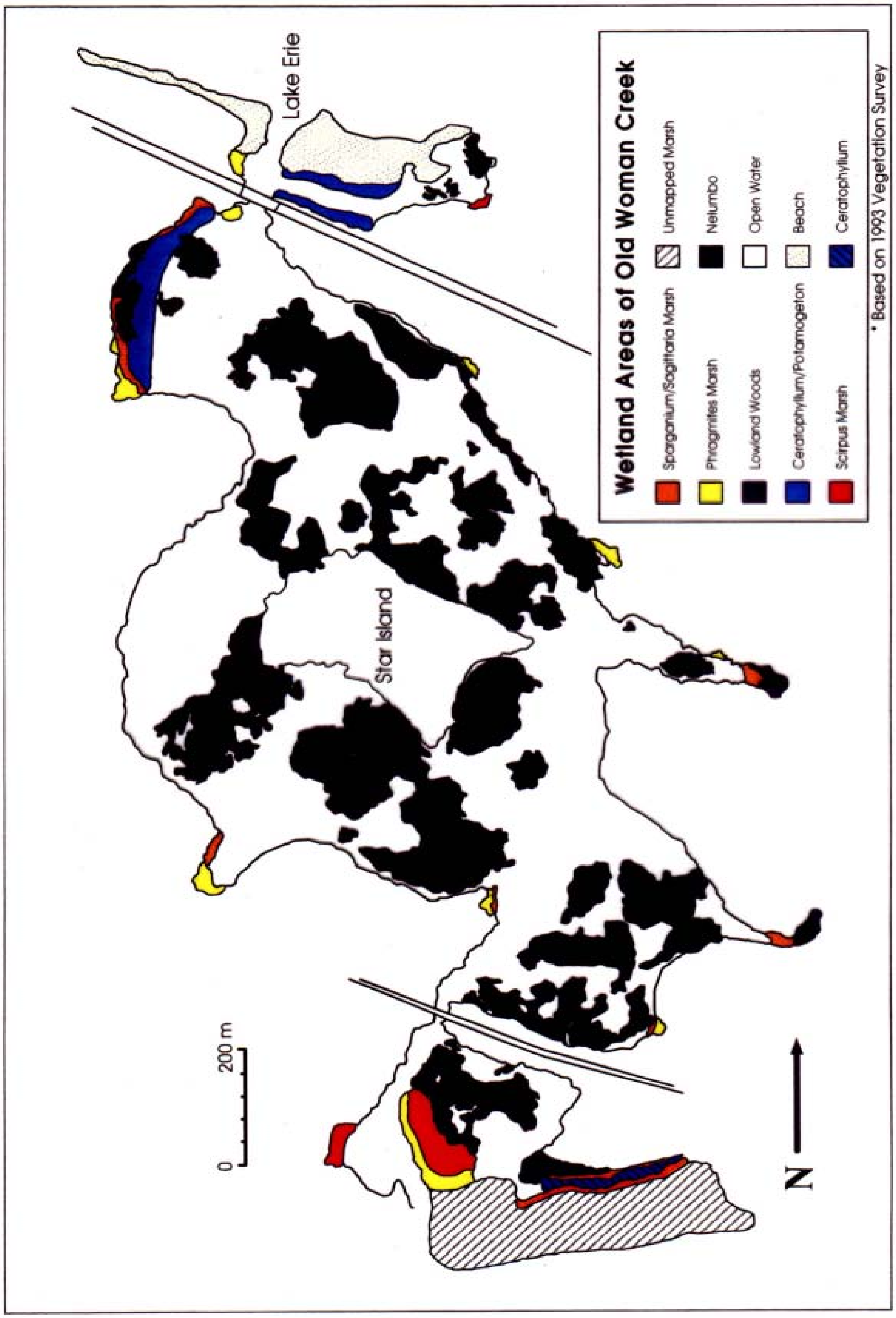


Figure 7.11. Detail of wetland vegetation distribution in Old Woman Creek estuary for 1993 (Whyte 1996).

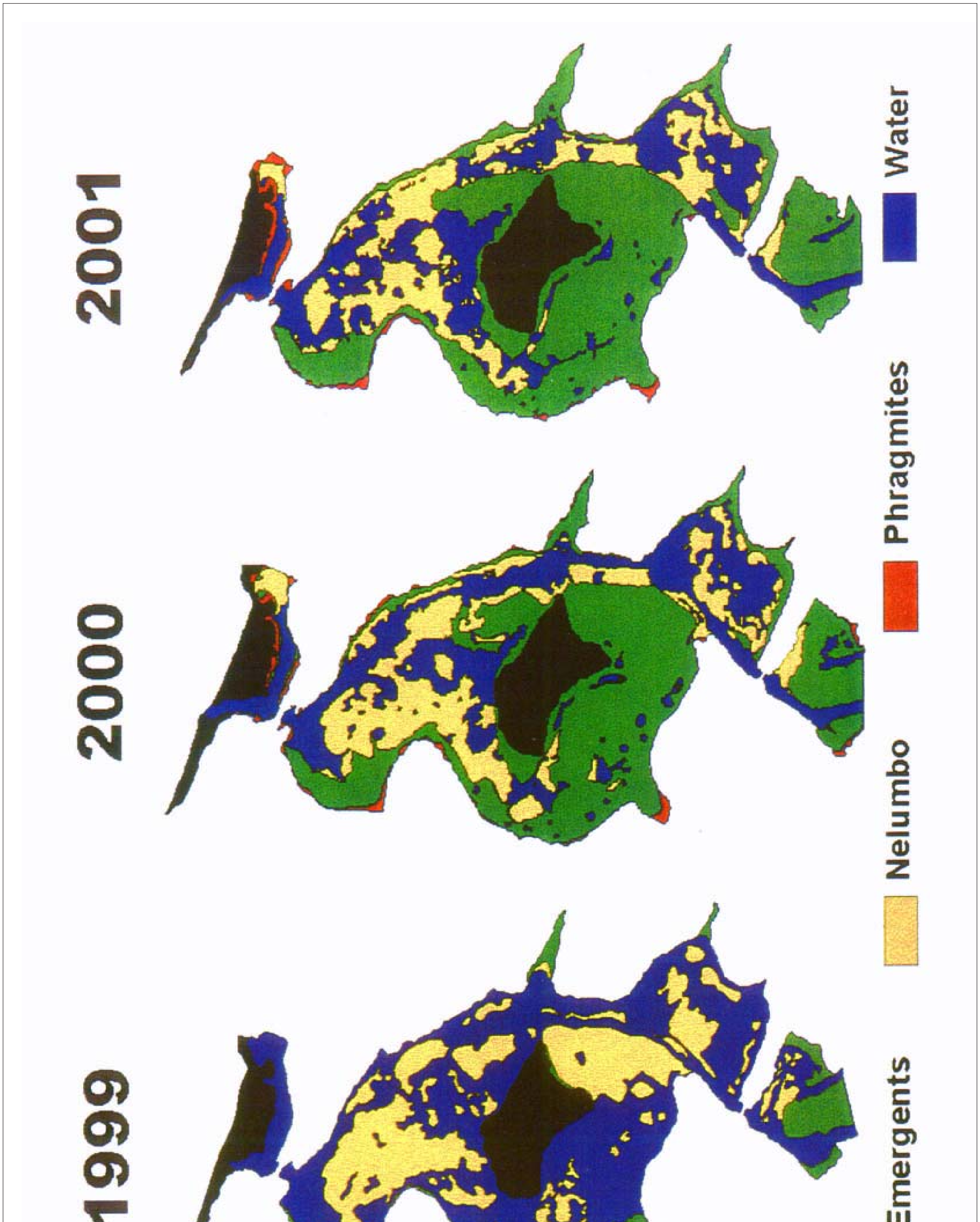


Figure 7.12. Distribution of macrophyte vegetation in Old Woman Creek estuary for 1999, 2000, and 2001 (Trexel-Kroll 2002).

INVASIVE SPECIES

Within Old Woman Creek estuary, three aquatic macrophyte species are deemed invasive species and have either been eradicated or monitored. *Lythrum salicaria* (purple loosestrife) and *Myriophyllum spicatum* (Eurasian water–milfoil) are both non-native, while *Phragmites australis* (common reed) has been considered a native species, but perhaps is an alien variety (Weinstein et al. 2002).

Lythrum salicaria, a major invasive of Lake Erie coastal wetlands, was first reported in Old Woman Creek by Marshall (1977). Although Marshall classified this species as common, it has yet to become a dominant species in the estuary. A control program has been in place at Old Woman Creek since the mid-1980's. When individual plants are discovered, they are eradicated—either by physically removing the plant or applying herbicides directly onto the plant. Despite this program, Whyte (1996) and Trexel-Kroll (2002) both reported this species in their vegetation studies in the estuary. It appears that this species can be controlled, but not eradicated in the estuary. Only when a lake-wide control program is initiated is there any chance of eradicating this invasive species from the estuary.

Myriophyllum spicatum was first reported in the estuary in 1992 in the northwest embayment (the small bay directly south and southwest of the U.S. Route 6 Bridge), although Marshall (1977) reported the presence of the native *Myriophyllum exalbescens* in the estuary. Whyte and Francko (2001) reported on the growth of *M. spicatum* from its first reported sighting in 1992 through 1997. Although this species was found in 1998 and 1999 by Klarer (unpublished), Trexel-Kroll (2002) did not report this species in her detailed study of the flora in this embayment during 2000 and 2001. Whyte and Francko (2001) pointed out that the available evidence supports the idea that Lake Erie is the source of this species for Old Woman Creek. All sightings have been near the mouth. The shallow nature of the wetland, exacerbated by the natural autumn and winter drawdown, frequently creates exposed mudflats. This, coupled with the winter periods where freezing temperatures and ice formation is common, creates an environment that is detrimental to the successful establishment of *M. spicatum*. They believed that the barrier beach may also play a major role in the dynamics of this invasive species in the estuary. In 1994, when no specimens were found in the estuary, the mouth was open through the barrier beach to Lake Erie only 44% of the year; whereas, in 1993 and 1995 it was open 58% and 77%, respectively.

Phragmites australis has probably been observed along the Lake Erie shores since before the arrival of the European explorers. Stuckey (1989) considered this species a native which had not significantly altered its distribution for the past 90+ years. This species was not found by Marshall (1977) in the estuary in the mid-1970s. It was believed to have entered the estuary in the mid-1980s and was first observed near the barrier beach (Klarer, personal observation). Whyte (1996) reported that small dense stands of *Phragmites* were confined to several low relief shoreline floodplain areas from 1993 through 1995. Trexel-Kroll reported that in 2000 and in 2001 with lowered water levels, *Phragmites* expanded into the newly created emergent zones in the wetland. By the end of the 2001 growing season this species was present in scattered beds throughout the estuary. She considered that this expansion was due in part to direct expansion of existing stands via rhizomes. In five separately monitored *Phragmites* beds in the estuary there was more than a four-fold increase in the size of the beds from 2000 to 2002 (40.7 m^2 in 2000 versus 182.5 m^2 in 2001). In new non-adjacent beds, translocation of rhizome fragments was probably the means of expansion. A *Phragmites* control program employing cutting and/or direct herbicide application to the stems has been underway since the late 1990s.

RELATIONSHIP OF AQUATIC PLANTS TO AQUATIC ANIMALS

Most of the leafy aquatic plants in Old Woman Creek estuary serve as shade or protection for fish, while some support algae or small animals which serve as food for fish. Krecker (1939) studied the invertebrate animal populations associated with aquatic plants in western Lake Erie. He noted that submerged, leafy types of vegetation are more densely populated than emergent, hard-surfaced, non-leafy forms. *Myriophyllum spicatum* (water milfoil) and *Potamogeton crispus* (curly pondweed) supported by far the densest populations (440 and 337 individuals per linear meter), followed by *Elodea canadensis* (common water-weed) and *Potamogeton pectinatus* (sago pondweed) with lesser, but substantial numbers (173 and 143/m). *Vallisneria americana* (wild celery)—a species not yet reported in the estuary, but present in western Lake Erie harbored only negligible numbers of aquatic invertebrates (9/m). Midge larva (Chironomidae) and freshwater annelids (Oligochaeta) comprised 45 and 44%, respectively, of the invertebrates living on *Potamogeton pectinatus*, one of the most common submersed plants in the estuary. The finely divided, narrow leaves of *Myriophyllum spicatum* and *P. pectinatus*, are well suited to these animals; midges cling to such leaves with their hook-bearing appendages and annelids coil about them. Conversely, *Vallisneria* offers a broad, smooth surface. The broader leaves of *Elodea* and *P. crispus* harbor a higher percentage of sessile forms (rotifers, bivalves, hydrozoans, and bryozoans) than narrow-leaved plants.

ESTUARY VEGETATION: PHYTOPLANKTON AND PHYTOBENTHOS

Plankton consists of the floating organisms in the estuary and Lake Erie—both plant (phytoplankton) and animal (zooplankton)—whose movements are more or less dependent on currents. While some phytoplankters have the ability to rise in the water column and certain zooplankters exhibit active swimming movements that aid in maintaining vertical position, as a whole, plankton tends to settle and most plankters are unable to move against a current. The phytoplankton of Old Woman Creek, the estuary, and the nearshore waters of Lake Erie consists of a diverse taxonomic assemblage of primarily microscopic algae. A fundamental characteristic of algae is the presence of photosynthetic pigments, such as chlorophyll (*a, b, c, & d*), carotenes, xanthophylls, and chromoproteins (phycocyanin and phycoerythrin). Chlorophyll *a* is the primary pigment in all oxygen-evolving photosynthetic organisms, and is present in all algae (Wetzel 2001). As discussed in Chapter 6, algal taxonomy at the division level is based on the specific combinations of other pigments with Chlorophyll *a*. This results in a characteristic color from which the common name of the algal divisions are derived: blue-green algae (Cyanobacteria), green algae (Chlorophyta), yellow-green and golden-brown algae and diatoms (Chrysophyta), euglenoids (Euglenophyta), yellow-brown algae and dinoflagellates (Pyrrhophyta), and red algae (Rhodophyta). Many of these groups also produce benthic forms associated with sediment, sessile on macrophytes, or attached to hard substrates for a portion of their life cycle.

The algae of Lake Erie have long been studied, with major studies dating back to the beginning of the 20th century and before (Vorce 1880, Pieters 1901, Snow 1903). Many of these early workers included adjacent coastal wetland areas in their studies of the lake algae. Although the first study concentrating on the phytoplankton in the tributaries and coastal areas of Lake Erie was conducted in the 1920's (Wright et al. 1955), very few studies have concentrated on the coastal wetlands of Lake Erie. Sullivan (1953) examined the plankton in the ten major estuaries along the Ohio shore of Lake Erie. From this work he concluded that the majority of the phytoplankton in the estuaries was of lake origin, being introduced into the estuaries by influxes of lake water. Kline (1981) in a study of the nearshore zone phytoplankton of the Lake Erie central basin also reported a strong similarity between lake and tributary phytoplankton populations. However, he did point out that the further the sampling site was from the lake, the greater the divergence from lake populations. Frederick (1975) examined changes in phytoplankton in the East Harbor up through 1974. Only 31% (47 of 151 taxa) of the previously reported algal species were still found at East Harbor by 1974, and there were 52 new records for Lake Erie. The changes he ascribed to human activities, particularly dredging activities in 1967.

Taft and Taft (1971) authored a taxonomic survey of the algae of the western basin of Lake Erie, which included various wetland areas on Bass Islands and Catawba Peninsula. The diversity of the algal flora in these wetland areas is readily demonstrated by the total number of species reported from each area (Table 7.3). The relative high number of Chlorophyceae in the marshes of South Bass Island and Middle Bass Island is due to the diversity of desmids found in these marshes, a group that is poorly represented in Old Woman Creek. The high number of the Euglenophyta found in Old Woman Creek may be a result of the transitory nature of phytoplankton populations in this estuary. A complete list of the algae reported from Old Woman Creek, its estuary, and the nearshore waters of Lake Erie is presented in Klarer et al. (2001).

The algae in a wetland area such as Old Woman Creek estuary occupy a series of overlapping habitats. Bolsenga and Herdendorf (1993) defined six algal communities in Lake Erie: phytoplankton, epipelon, epiphyton, epilithon, epipsammon, and metaphyton (Figure 7.13). The phytoplankton includes all algae

TABLE 7.3. RELATIVE ABUNDANCE OF ALGAL SPECIES FOR SEVEN WESTERN LAKE ERIE MARSH AREAS

Taxonomic Group	South Bass Island	Middle Bass Island	North Bass Island	Kelleys Island	Pelee Island	Catawba Penisnula	Old Woman Creek
Cyanophyta	56	36	20	15	6	22	44
Rhodophyta	1	0	1	1	0	0	0
Chrysophyta-Chrysophyceae	19	15	10	4	0	2	31
Chrysophyta-Xanthophyceae	6	7	7	3	7	1	6
Chrysophyta-Bacillariophyceae	Not determined	Not determined	Not determined	Not determined	Not determined	Not determined	(311)
Pyrrhophyta-Dinophyceae	3	5	2	0	1	1	10
Cryptophyceae	1	0	0	0	0	0	21
Euglenophyta	11	6	4	4	1	0	77
Chlorophyta-Chlorophyceae	238	194	101	80	46	86	171
(Chlorophyta-Desmidiaceae)	42	48	18	40	29	38	15
Chlorophyta-Charophyceae	8	4	0	0	0	9	0
Totals	343	267	145	107	61	121	351 (662)

Data Source: Modified from Herdendorf (1987) with the addition of Old Woman Creek estuary data found in the water column. This community will include many members of the other three communities that have become detached and washed into the phytoplankton. The epipelon encompasses the algae that grow in and on the soft sediments. Epipelic algae may be very important in regulating the movement of nutrients from the anaerobic sediments to the overlying water (Wetzel 1996). Many of these algae are motile flagellates that will also be found in the phytoplankton during some part of the year. The epiphyton and metaphyton refer to the algae that grow attached (epiphyton) or associated with but not attached (metaphyton) to the aquatic plants. Epilithic algae grow on rocks while episammic algae grow on sand grains or the intersitial spaces between grains. In Old Woman Creek, preliminary work has been conducted on all but the epipsammon and metaphyton algal communities.

PHYTOPLANKTON

Studies of phytoplankton in Old Woman Creek estuary (Klarer and Millie 1994b, Klarer 1989, Klarer 1983, Klarer unpublished data) demonstrate high variability in this community. Multiple peaks were observed throughout the year (Figure 7.14). The time and duration of these peaks seemed highly erratic. Despite this variability, the dominant species were similar from year to year. Through most of the year, the phytoplankton was dominated by several small *Cyclotella* species. In the later part of the spring, as water temperatures rose toward summer levels, the Cryptophytes: *Cryptomonas* spp. and *Rhodomonas minuta* var. *nannoplanctonica* became widespread. During the summer and autumn *Aulacosiera* spp., particularly *A. alpigina*, were also common in the phytoplankton. Members of the Chlorophyta and Cyanophyta were common in late summer/early fall during some years but not others.

A study examining the role of storm events on phytoplankton populations in the estuary was undertaken in 1984 after it was observed that fluctuations in population numbers often coincided with fluctuations in turbidity. This, coupled with the paucity of Chlorophyta and Cyanophyta normally dominant in Lake Erie proper, suggested that storm runoff events were a major factor in regulating estuarine phytoplankton (Klarer and Millie 1994b).

Storm water flowing through the estuary flushed out much of the existing populations, but at the same time carried nutrients into the estuary allowing the surviving populations to rapidly repopulate the estuary. In one of the sampled storms, population numbers in the lower estuary increased within two weeks of the

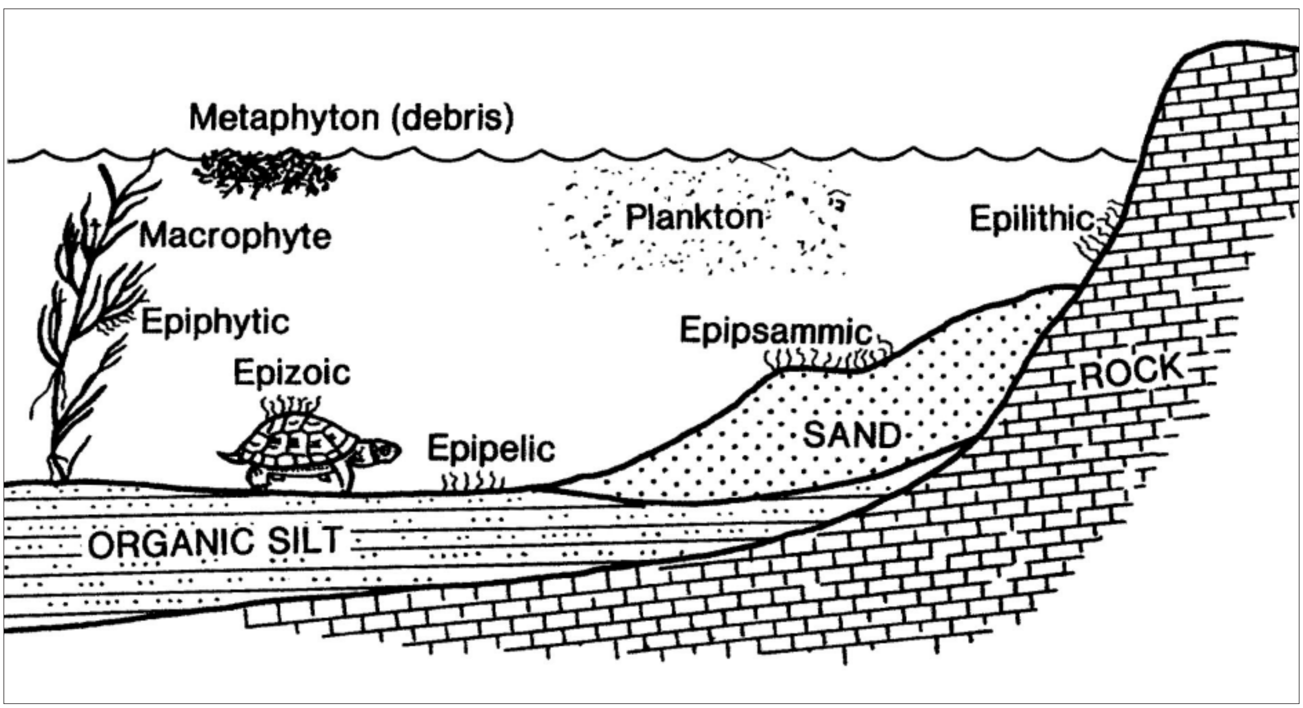


Figure 7.13. Algal communities in Old Woman Creek estuary and watershed (after Bolsenga and Herdendorf 1993).

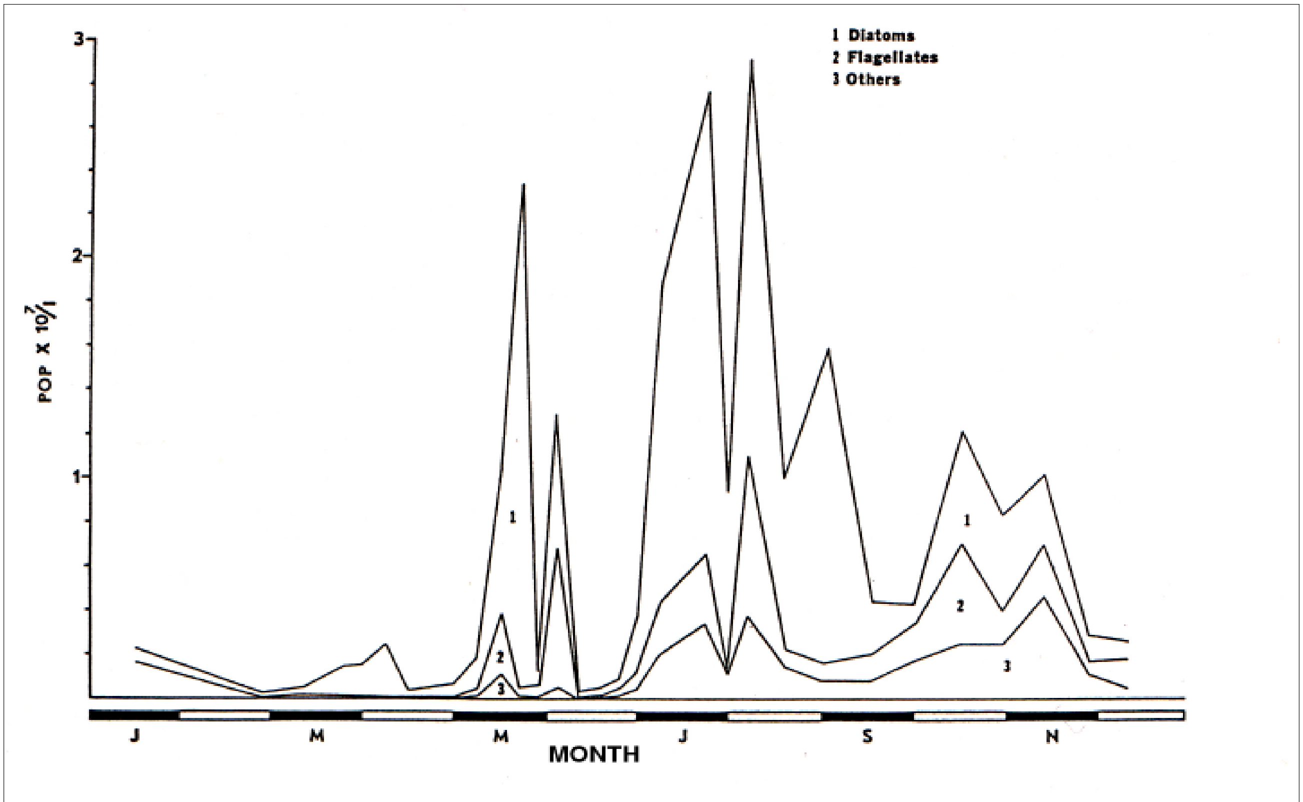


Figure 7.14. Phytoplankton populations in Old Woman Creek estuary for 1980 exhibiting multiple peaks throughout the growing season (after Klarer 1983,1989).

storm's passage to over four times pre-storm numbers; this rapid repopulation was not observed in the upper reaches of the estuary (Figure 7.15). The researchers attributed this to a lack of backwater refugia in the upper reaches of the estuary, which would have provided the surviving algae necessary for rapid recolonization.

Circumstantial evidence suggests that the agricultural chemicals applied in the Old Woman Creek watershed may be influencing both the numbers and composition of the phytoplankton. Agriculture is the dominant land-use pattern within the Old Woman Creek watershed. The short-and long-term impacts of agriculturally-derived chemicals on wetlands and their resident organisms have only recently been addressed (Krieger 1989, Krieger et al. 1989). Sieburth (1989) proposed that agricultural chemicals, when introduced into coastal embayments, potentially raise the growth ceiling of specific phytoplankton through nutrient input while killing predators, thereby allowing phytoplankton to reach maximum growth unrestrained by grazing.

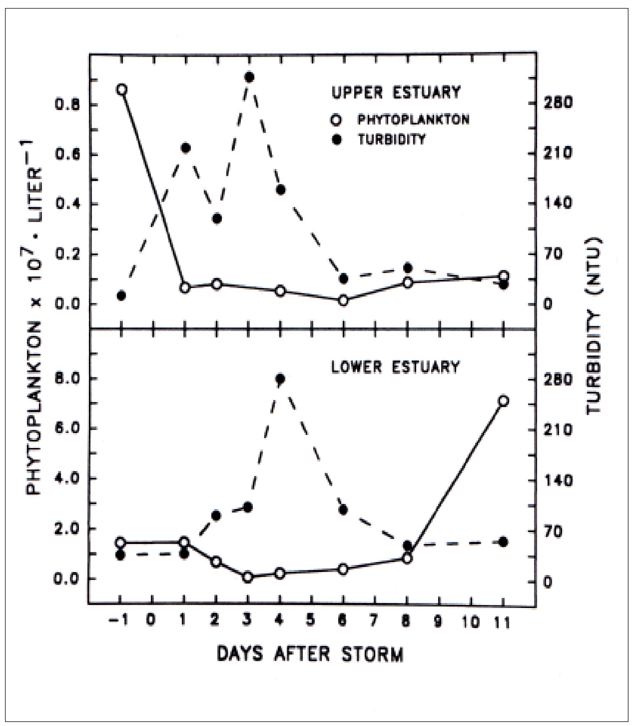


Figure 7.15. Phytoplankton standing crop in response to storm-water inflow through Old Woman Creek estuary (Klarer and Millie 1994b).

In Old Woman Creek, the flushing of the estuary would undoubtedly remove potential predators from the system. However, differential growth of phytoplankton taxa in response to agricultural chemicals might occur. Fertilizers and herbicides (particularly triazines) are routinely applied to agricultural lands within the watershed during spring planting. Although triazine residues are present in the estuary throughout the year, storm waters import a significant chemical load (Krieger 1984). Geographical races of phytoplankton and phytoplankton taxa in various physiological states display distinct growth and photosynthetic responses to differing concentrations of triazine herbicides (e.g. Millie and Hersh 1987; Millie et al. 1992)—it is highly likely that individual taxa display distinct responses as well (Hersh and Crumpton 1989). The herbicides introduced by storm waters may alter the water chemistry in Old Woman Creek enough to cause changes in the composition and physiology of the populations that potentially may recolonize the estuary. This may explain an observed selective increase of *Cryptomonas erosa* and *Cyclotella* spp. after a spring storm event, which closely followed herbicide applications in the watershed.

Klarer and Millie (1994a) examined summer and autumn phytoplankton populations in the estuary in 1992, which was a wet year with frequent storm flushing during the summer and fall, and in 1993, which was a dry year when the mouth was closed for much of the summer (Table 5.8). During July, August, and September 1992, the phytoplankton was dominated by diatoms, particularly the smaller *Cyclotella* species. The Chlorococcales (green algae containing the genera *Scenedesmus*, *Pediastrum*, and other common phytoplankton species) were present only in very small numbers. In 1993, however, when the mouth was closed for much of this 3 month period, the Chlorococcales formed a significant part of the phytoplankton. The Cyanophyta were also much more common in 1993. The lack of storms influencing the estuary permitted the estuary to become more physically stable. Under these conditions, biological interactions between the various phytoplankton species and their grazers would become more significant. When the mouth was open, there was also a much higher proportion of benthic or attached diatoms in the phytoplankton. This supports the hypothesis that periods when the mouth is open correspond to periods of increased physical instability in the estuary, in that physical processes are more important than biological ones in regulating the composition of the phytoplankton.

In the nearly two decades since the inception of the monitoring program at Old Woman Creek, Lake Erie has undergone tremendous change, both in nutrient levels and in phytoplankton composition. The massive mats of the blue-greens *Aphanizomenon* and *Anabaena*, which were so common in the 1970s, have disappeared. Filamentous diatoms and small cryptophytes are more prevalent. Nutrient levels in the waters of Lake Erie have declined. With these changes in the receiving lake as a backdrop, Klarer (1999) studied the phytoplankton in the Old Woman Creek estuary to determine if similar changes had occurred in the estuary. He reported that the total population numbers were very similar during the two 3-year periods of study (1981-1983 and 1995-1997) (Figure 7.16). The relative contribution of the various algal groups, however, was quite different during the two time periods. In both study periods, the diatoms, particularly *Aulacoseira alpigena* and various smaller *Cyclotella* species, was the dominant group through much of the spring and early summer. In the early 1980s the diatoms progressively dropped in relative importance through the year from late spring onward; while in the late 1990s, diatoms remained the dominant group through the year. In the early 1980s green algae, primarily chlorococcales such as *Scenedesmus*, *Didymocystis*, *Lagerheimia*, and *Crucigenia*, and the blue-greens, including *Merismopedia* and various *Oscillatoria* species, were increasingly more important through the summer and fall (Figure 7.17). This again can be related back to storm activity in the watershed. During the years 1981-1983 diminished rainfall in the watershed resulted in the mouth remaining closed for a major part of the summer. Rainfall amounts in 1995-1997 were adequate to keep the mouth largely open through the summer growth period. The changes reported in Lake Erie were not observed in the estuary. This study again highlighted the over-riding importance of physical processes in regulating the phytoplankton in Old Woman Creek estuary.

Wind-induced waves in the lake can push lake water into and up the estuary. Lake water is normally lower in conductivity, higher in pH, and lower in metals. In addition, the phytoplankton in Lake Erie is noticeably different from that in the estuary, therefore,

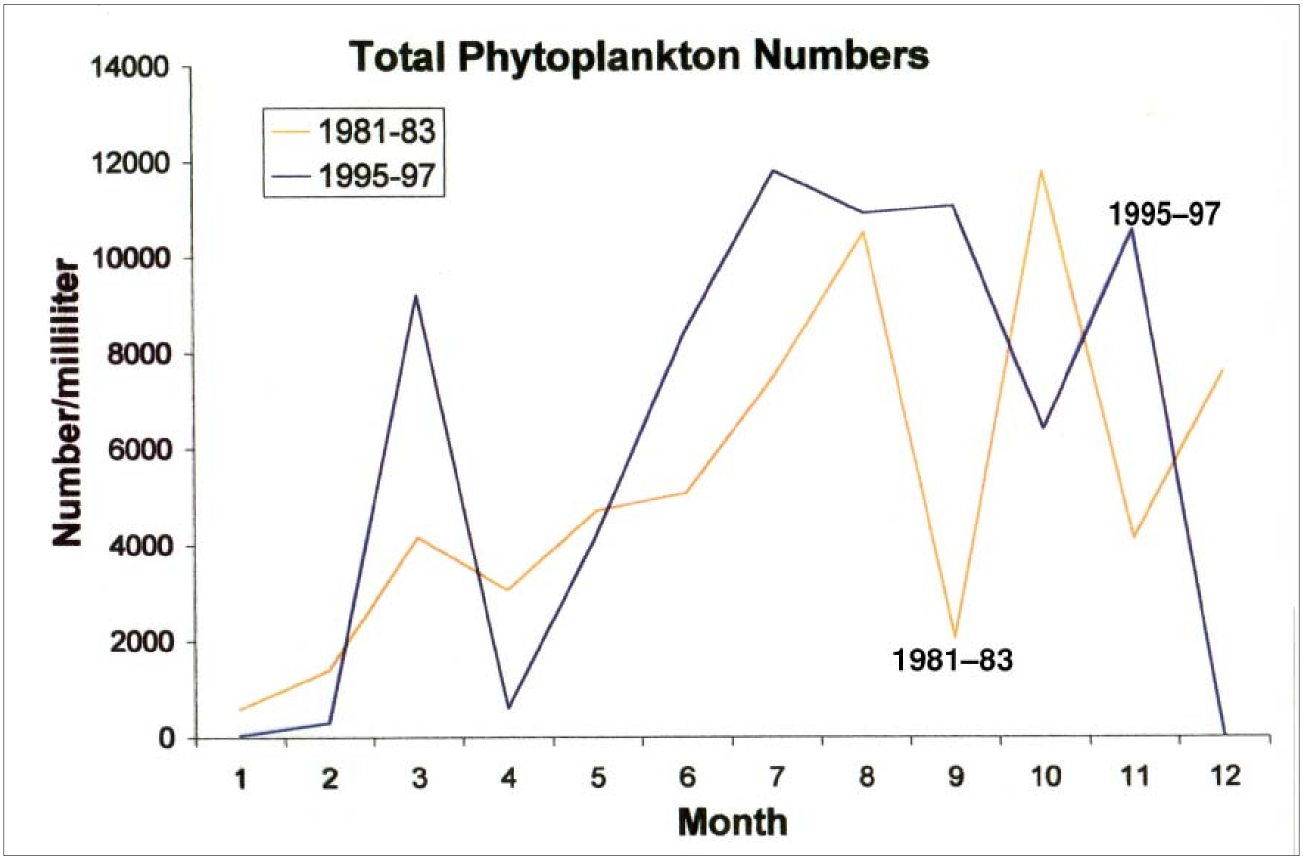


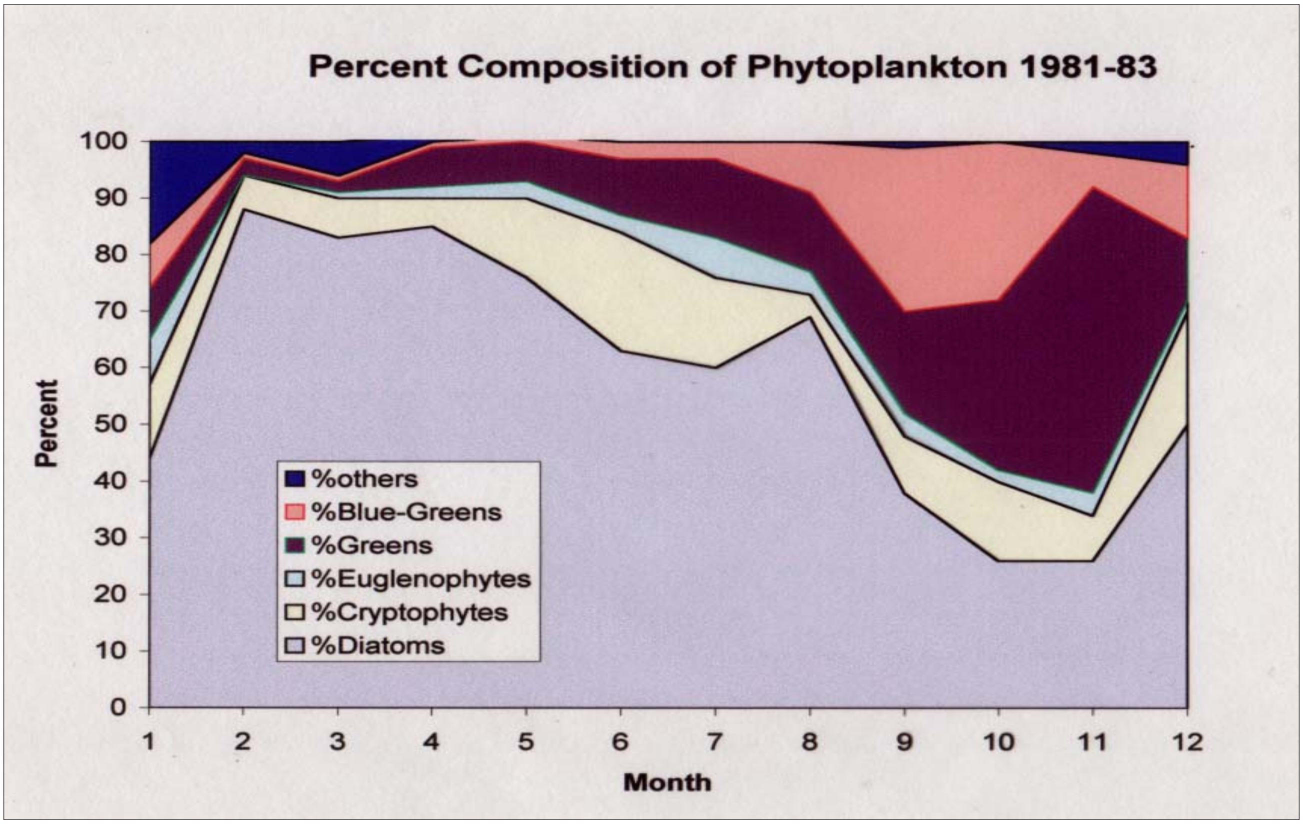
Figure 7.16. Total phytoplankton abundance in Old Woman Creek estuary during two time periods exhibiting relatively consistent numbers.

the presence of certain species such as *Stephanodiscus binderanus* or *Fragilaria crotonensis* is usually a reliable indicator of lake water intrusion.

In summary, the phytoplankton populations in the Old Woman Creek estuary seem to be storm regulated. The waters and the composition of the phytoplankton in the estuary are largely determined by storm activity, either on the lake or in the watershed. Storms and storm runoff in the estuary largely determine the numbers and species composition of the phytoplankton. With the watershed averaging more than one storm a month (see Table 4.5), the phytoplankton is normally dominated by "pioneer" species including smaller pigmented flagellates and smaller centric diatoms for much of the year. Only when storm runoff diminishes and the mouth closes does the physical habitat in the estuary become more stable. It is at these times that biological interactions between the phytoplankton itself and its grazers may become more important in determining species composition and numbers.

EPIPELON

Jensen (1992) undertook a study of the epipelon and factors that might regulate these communities in Old Woman Creek estuary. During the summer/fall sampling regime, diatom species dominated the populations, with *Nitzschia* spp., particularly *N. palea* ($4x10^5/mm^2$–August) and *N. reversa* ($1.5x10^6/mm^2$) being most common. The blue-green filamentous alga *Oscillatoria* sp. ($2.9x10^5/mm^2$) was also a dominant species at some of the sites during the late summer-early autumn period. The flagellated Euglenophytes were present in small to moderate numbers in this community. Nutrient addition studies were inconclusive. Increasing nitrate levels in the overlying waters increased diatom numbers and biovolume, but increasing phosphorus levels in the sediments also caused a marked increase in the epipelon. These contradictory results underline the need for caution when interpreting nutrient addition studies. Other factors may be influencing this community, and thus masking nutrient trends. Both shading and turbulence decreased the numbers and diversity of the epipelon.



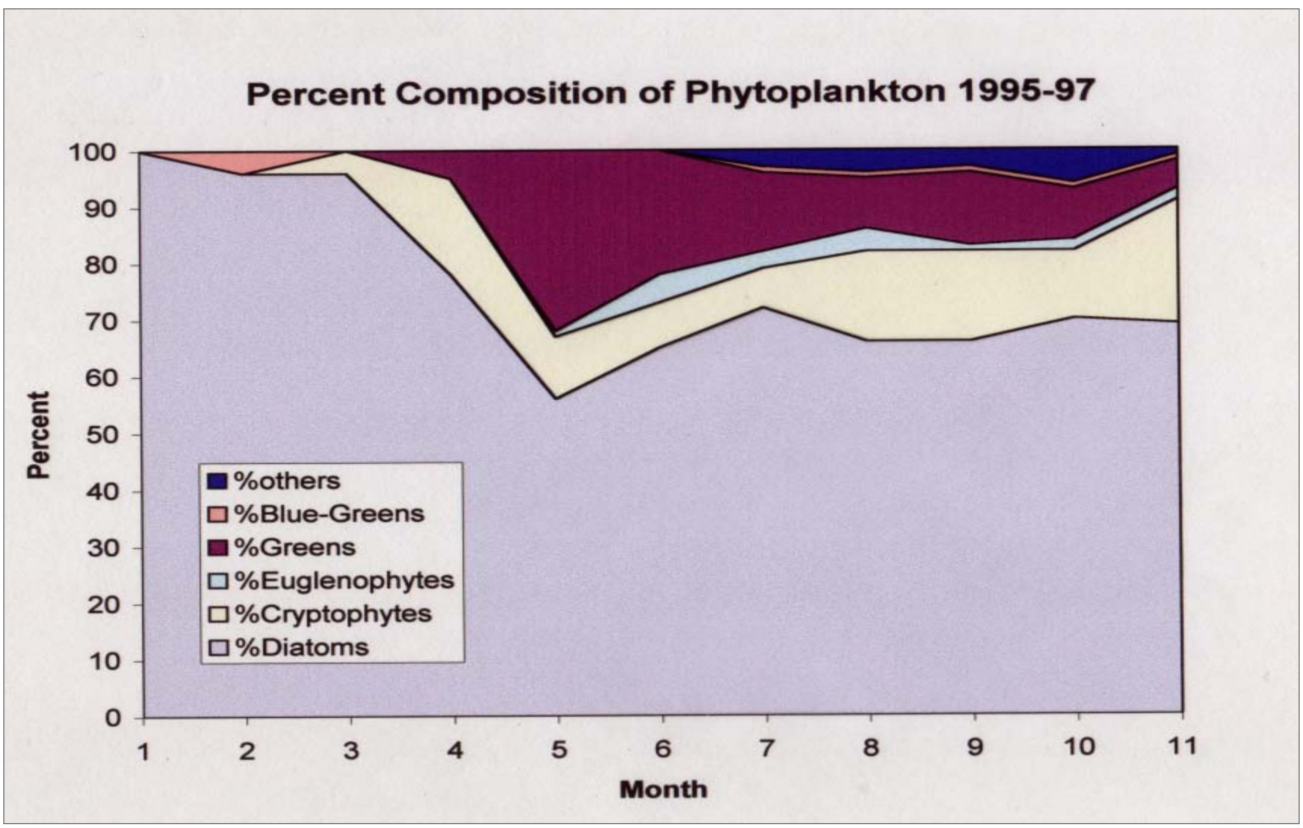


Figure 7.17. Percent composition of phytoplankton in Old Woman Creek estuary for 1981-1983 (showing autumn decline in diatom dominance) and 1995-1997 (showing continued dominance of diatoms in the autumn).

EPIPHYTON

Two studies on the epiphyton attached to the aquatic macrophytes in Old Woman Creek estuary were conducted in the early 1980s. Millie and Klarer (1980) surveyed the epiphytic algae growing attached to one algal (*Cladophora*) and nine different macrophyte hosts during June 1980. This study indicated that there was very little evidence of host specificity, but there was site specificity. In most areas of the estuary, *Gomphonema parvulum* and *Nitzschia* species (*N. filiformis*, *N. amphibia*, *N. dissipata* var. *media*, and others) dominated the epiphyton flora. In the summer of 1999, Reed (1999) studied the epiphyton growing attached to *Nelumbo* in several areas of the estuary. She reported that diatoms in the genus *Nitzschia* still dominated the epiphyton attached to *Nelumbo*, but the species included *N. palea*, which was not as prevalent in the early 1980s and *N. filiformis*, which was also a dominant in the earlier studies. The very high variability between replicates in the 1999 study suggested that environmental factors and not specific interactions between the host macrophyte and the epiphyton seem to regulate the species abundance and diversity in the epiphyton. Reed reported that there was a significant relationship between the sites and the populations in July and August of 1983 and July and August of 1999, suggesting that similar conditions resulted in similar populations. However, the populations from June 1983 were not similar to any other populations in either 1983 or 1999. The cause of this dissimilarity is not known. In June, just south of U.S. Route 6 and just south of the railroad *Thalassiosira pseudonana*, a brackish water species that has become common in Lake Erie, dominated the flora. Klarer (1981) studied the epiphyton attached to *Nelumbo* stems, both the dead stems of the previous year and the growing stems of the present year during 1980. The dead stems remained standing through the mid-spring. During this early spring period, the diatoms *Gomphonema olivaceum* and *Diatoma elongatum* and the green algae *Stigeoclonium* sp. dominated the populations growing on the dead stems. As with the earlier study by Millie and Klarer (1980), during the June period, the diatoms *Gomphonema parvulum* and *Nitzschia* species dominated the epiphyton. As the water temperatures approached summer maximum levels, the green algae *Stigeoclonium* was replaced by *Oedogonium* sp. and *Spirogyra* sp. The blue-green algae *Phormidium* sp. also became common with increasing water temperatures. In summary, the epiphyton in Old Woman Creek estuary are characteristic of a wetland that is eutrophic and slightly alkaline. The numerical dominance of both *Gomphonema parvulum*, a facultative nitrogen heterotroph, and *Nitzschia filiformis*, an obligate nitrogen heterotroph, suggest a low to moderate level of dissolved organic compounds in the water, at least through early to mid-summer.

EPILITHON

Klarer (1981) also examined the epilithon (algae growing attached to rocks) in the creek proper. In many river and stream systems, particularly in the faster moving portions, the epilithon are the dominant primary producers. In Old Woman Creek, the creek bed was dominated by the diatom *Gomphonema olivaceum* in the late winter and early spring. With increasing light levels and water temperatures, the green algae *Cladophora glomerata* became the dominant species, primarily due to its size—numerically it was never a major component of the population, but the large cell size of this algae made it the dominant in biomass. Attached to this algae was an epiphytic flora that was dominated by diatoms, particularly *Rhocosphenia abbreviata* and *Cocconeis placentula*.

PRIMARY PRODUCTIVITY IN THE ESTUARY

In a freshwater wetland system, the phytoplankton is frequently considered a minor component of the wetland system, if considered at all (Mitsch and Gosselink 1993). In two earlier data syntheses on the coastal wetlands of Lake St. Clair (Herdendorf et al. 1986) and the coastal marshes of western Lake Erie (Herdendorf 1987) the phytoplankton were considered a significant, but not dominant, source of organic carbon. Phytoplankton can have a major impact on the food web of the estuary—whether the food web is grazer-based or detrital-based (Wetzel 1983,1992). As reported by Reeder (1990), the primary source of autotrophic carbon in the Old Woman Creek estuary was the phytoplankton. This would suggest a grazer-based food web. The method used by Reeder to determine macrophyte productivity—above ground harvest—tends to underestimate the net productivity of *Nelumbo* due to the propensity of these rhizomatous perennials to translocate a significant part of the photosynthate to the underground root-rhizome system (Francko and Whyte 1999). Francko and Whyte (1999), in a later study of Old Woman Creek estuary, concluded that the macrophytes were the dominant producers in the estuary; thus, the food web would be detrital based. Although these two studies seem to contradict each other, it is very likely that each is appropriate for the particular year being studied. Macrophytes fix more carbon per unit area, on the order of 5 to 10 times more carbon (Francko and Whyte 1999); so, the relative importance of the two producers is dependent upon the percentage of macrophyte cover (Table 7.1).

From the late 1970s through the late 1980s, the estuary was most likely phytoplankton dominated; but from the early 1990s through 2001, macrophytes were dominant. When considering the food available for the next level in the food web, production measurements of *Nelumbo*—or any other aquatic macrophyte that has an extensive perennial underground rhizome or root system—must consider that a portion of the production will be translocated into the root/rhizome system and thus will be unavailable to the next food web level. Although Reeder's (1990) macrophyte production rates underestimated the available food produced because his method could not account for leaf fall prior to harvesting, Francko and Whyte's (1999) macrophyte production rates probably overestimated the food available for the next level for the reason that an unknown portion of the macrophyte production was transferred to the underground rhizome where it was unavailable for consumption by the next level of the food web.

The hypertrophic nature of the estuary is readily demonstrated with data obtained from the data loggers. The diurnal changes in oxygen and pH in the estuary (Figure 7.18) are characteristic of a system where production is very high. During the daylight hours, oxygen levels in the water rise because high primary productivity produces oxygen at a greater amount than respiration can take it up, or it can diffuse into the atmosphere. At the same time, free carbon dioxide in the water is taken up by the primary producers faster than it can be replaced by respiration and diffusion from the atmosphere, which causes the pH of the water to rise. At night, respiration reverses the trend because photosynthesis has ceased. Oxygen is taken up from the water faster than it can be replaced by diffusion from the atmosphere; thus, oxygen levels drop to very low levels with minimal concentrations occurring just prior to sunrise. At night, respiration releases free carbon dioxide back into the water faster than it can diffuse into the atmosphere, thus lowering the pH.

Data logger data also emphasize the importance of storm events in the ecology of the estuary. Figure 7-19 is a series of graphs of the data collected over a two-week period in late August to early September 1998 from a site in the upper estuary. A storm on August 25, 1998 resulted in the influx of storm water, as demonstrated by a rise in water level. This rise corresponds to both an increase in turbidity and a drop in specific conductivity. The dampening of the oxygen and pH diurnal variations after the passage of the storm (August 27 to September 1) suggests that the storm water washed away existing phytoplankton populations. About one week after the storm, the previous diurnal variations in both of these parameters returned, suggesting the re-growth of phytoplankton in the upper estuary.

Phytoplankton—Zooplankton Interaction

Havens (1991c) examined the role of zooplankton in the food web and energy flow in Old Woman Creek estuary. His work supports Reeder's contention of the importance of the phytoplankton in the estuary. Zooplankton community filtration rates here were among the highest reported in the literature with herbivores filtering up to 73% of the water column per hour. Despite this high rate there was no "clear water" period observed in the estuary. This was attributed to the very high algal productivity due to continual internal and external nutrient loading through the sampling period. These rapid rates also indicated a rapid energy flow from the phytoplankton to the zooplankton. In May and June, nauplii and small cladocerans dominated zooplankton filtration activity, but by July rotifers had become the dominant group. They maintained this dominance through August. In September the rotifers and small cladocerans were co-dominant. Through the summer and into the autumn, rotifers and the smaller cladocerans dominated the zooplankton filtration activity.

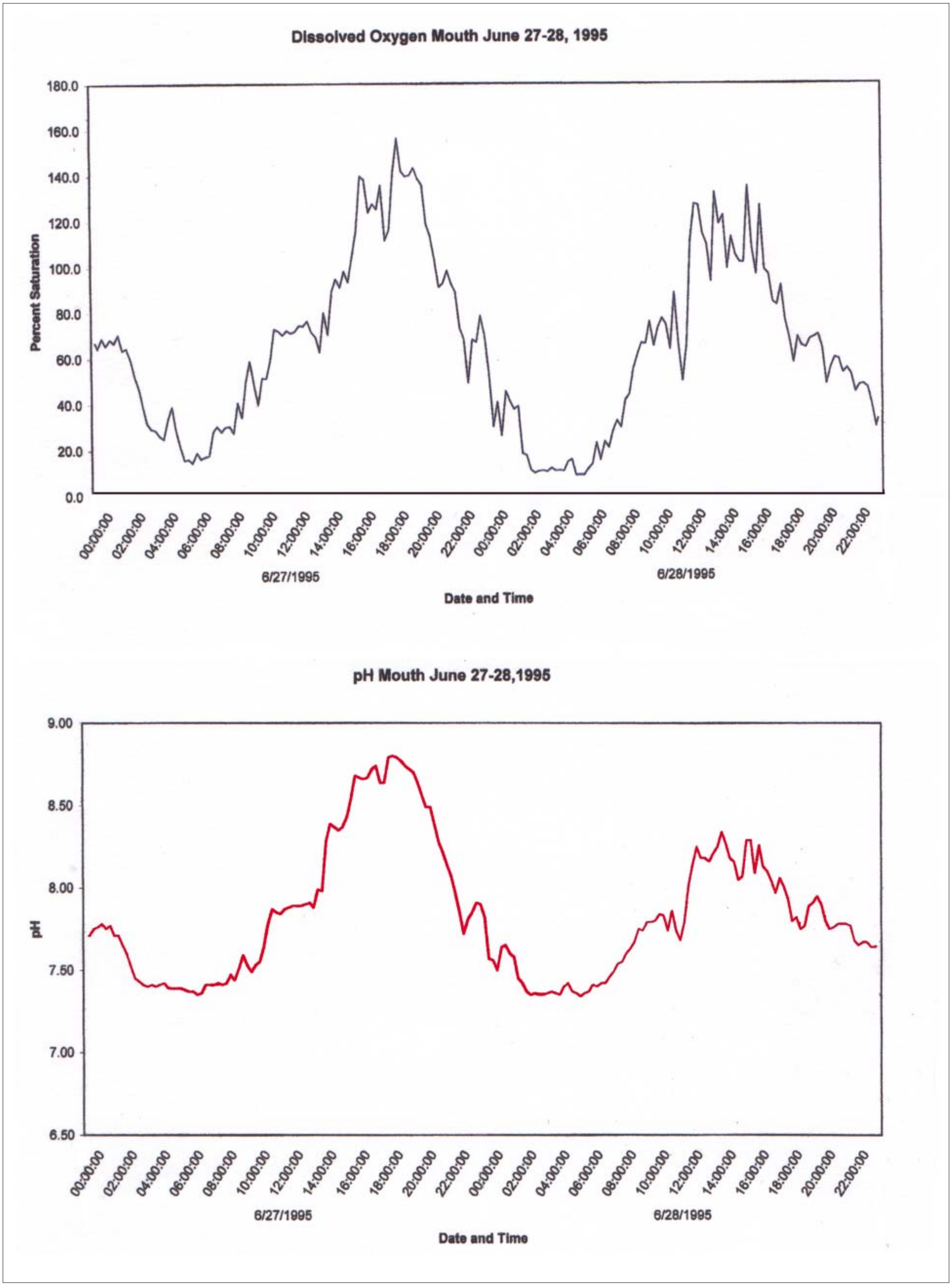


Figure 7.18. Diurnal changes in oxygen (percent saturation) and pH in lower Old Woman Creek estuary.

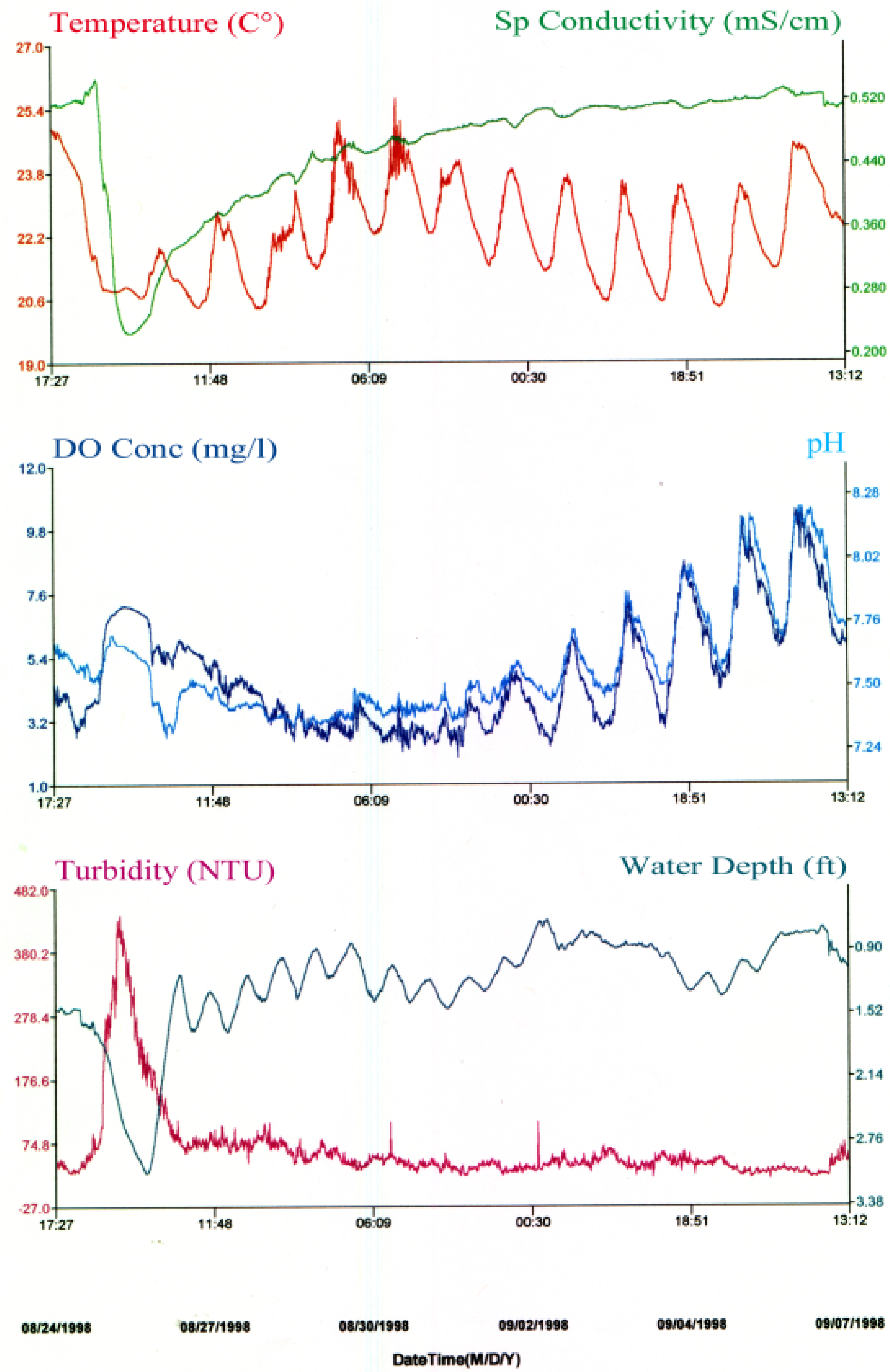


Figure 7.19. Impact of storm runoff on upper Old Woman Creek estuary during a two week period in late summer 1998.

NOTE: Upper graph—temperature (left vertical scale) and specific conductivity (right vertical scale); middle graph—dissolved oxygen (left vertical scale) and pH (right vertical scale); and lower graph—turbidity (left vertical scale) and water level (right vertical scale), water depth increases toward bottom of graph.

Invertebrate Ecology of the Estuary

Freshwater invertebrates are ubiquitous and often abundant members of the benthic, planktonic, periphytonic, and neustonic communities of Great Lakes estuaries and coastal wetlands. They serve an important role in the transfer of energy and materials in these habitats and also provide a major food resource for fish and waterfowl (Krieger 1992). Despite their apparent importance, comparatively little is known of the distribution and ecology of invertebrates in Great Lakes estuaries. However, in recent years a number of studies have been initiated at Old Woman Creek estuary which address the zooplankton and zoobenthos in a coastal wetland, including Miller (1982), Havens (1991a,b,c,d), Kepner and Pratt (1993,1996), Klarer (1989), Krieger (1985,1992), and Krieger and Klarer (1991,1992,1995). Terrestrial invertebrates in the Old Woman Creek watershed have received even less attention, with only three studies of limited scope, Gray et al. (1997), Phillips (1998), and Phillips and Nemire (1999). The following discussion of invertebrates in the estuary and watershed is based on the results of these investigations and several specialized studies by Bur et al. (1986), Bur and Klarer (1991), Ingold et al. (1984), and Miller et al. (1984).

Zooplankton

While some zooplankters exhibit active swimming movements that aid in maintaining vertical position, as a whole, plankton tends to settle and most plankters are unable to move against a current. As animals, zooplankton are not primary producers and are either herbivores (phytoplankton feeders), carnivores (zooplankton feeders), or omnivores (phytoplankton and zooplankton feeders). Excluding protozoans, which have been discussed earlier in this volume (Chapter 6), there are three major groups of zooplankton capable of some degree of locomotion: the rotifers, and two microcrustacean forms (cladocerans and copepods). Rotifers are classified as a distinct phylum (Rotifera), while the other two groups are in the phylum Arthropoda, class Crustacea, and subclasses Brachiopoda (cladocerans) and Copepoda (copepods).

Zooplankton in the estuary are dominated by small cladocerans and rotifers for much of the year. Many of the most important rotifer species in the estuary have previously been described as "pioneer species"—species that have rapid reproduction rates and can quickly repopulate an area (Hanazato and Yasuno 1990, Ferrari et al. 1984; as cited in Havens 1991d). The dominance of these species of rotifers and small cladocerans supports the hypothesis that the estuary is a storm driven system. The predominance of flagellates and small diatoms in the phytoplankton in the estuary should favor the dominance by the larger cladocerans, but the larger cladocerans do not have a rapid reproduction rate and so frequent flushing denudes the estuary of these organisms. Although the storms and other physical forces are critical in determining the composition of the zooplankton in the estuary, there appears to be biological interactions also affecting zooplankton distribution. There were greater numbers of the small cladocerans in the vegetated areas than in the open water areas. Havens (1993) clearly demonstrated the importance of fish predation in determining this distributional pattern.

Community Structure

The zooplankton community of Old Woman Creek estuary was compared with that of the nearshore (wave zone) of Lake Erie adjacent to the mouth of the estuary by Krieger (1985). He found that the crustacean zooplankton communities were distinctly different both in species composition and density between the upper estuary and the lake (Table 7.4). Old Woman Creek estuary is dominated by two cyclopoid copepods (*Acanthocyclops vernalis* and *Tropocyclops prasinus mexicaus*), a calanoid copepod (*Skistodiaptomus pallidus*), and two cladocerans (*Diaphanosoma birgei* and *Moina micrura*), whereas nearshore Lake Erie is characterized by a cyclopoid copepod (*Diacyclops thomasi*), a calanoid copepod (*Eurytemora affinis*), and bosminid and daphnid cladocerans (*Bosmina longirostris*, *Daphnia galeata mendotae*, and *D. retrocurva*). The lower estuary represents an ecotone (Odum 1971), in that it possesses a zooplankton community intermediate between the lake and the upper estuary. Of 40 crustacean zooplankton species identified in the lake and estuary, only 18 were found in both the lake and estuary (Krieger 1992).

The difference in zooplankton communities is also manifested in terms of the timing of life cycles. During early summer *Acanthocyclops vernalis* and *Diacyclops thomasi* are the dominant adult copepods in the estuary, and the most abundant cladocerans are

TABLE 7.4. MAXIMUM ABUNDANCE OF CRUSTACEAN ZOOPLANKTON SPECIES IN OLD WOMAN CREEK ESTUARY AND ADJACENT LAKE ERIE

	Individuals Per Liter		
	Upper Estuary	**Lower Estuary**	**Nearshore Lake Erie**
CYCLOPOID COPEPODS			
Acanthocyclops vernalis	44.4	67.0	21.7
Cyclops varicans rubellus	4.1	0.8	0.4
Diacyclops thomasi	7.0	125.5	31.0
Mesocyclops edax	1.2	2.5	8.9
Tropocyclops prasinus mexicanus	4.6	2.5	2.1
CALANOID COPEPODS			
Diaptomidae (immature copepodids)	47.3	48.0	23.0
Eurytemora affinis	0.6	2.6	17.1
Leptodiaptomus ashlandi	0.3	1.4	1.3
Leptodiaptomus minutus	–	0.3	0.4
Leptodiaptomus sicilis	–	0.2	0.6
Leptodiaptomus siciloides	0.3	0.7	0.6
Skistodiaptomus oregonensis	0.1	0.7	1.8
Skistodiaptomus pallidus	9.8	8.8	–
CLADOCERANS			
Alona quadrangularis	–	–	1.1
Alonella setulosa	–	–	1.4
Bosminidae spp. (mucronate)	19.7	54.6	76.5
Ceriodaphnia recticulata	–	0.3	–
Chydorus sp.	1.6	1.3	12.4
Daphnia galeata mendotae	0.7	1.1	20.7
Daphnia parvula	0.4	–	–
Daphnia retrocurva	1.6	1.0	15.8
Diaphanosoma birgei	19.7	20.9	2.8
Eubosmina coregoni	1.4	2.9	10.5
Ilyocryptus sordidus	0.4	–	0.5
Moina micrura	21.5	9.6	–
Pleuroxus denticulatus	0.4	0.6	–
Scapholeberis mucronata	–	0.4	

Data Sources: Krieger (1985); Krieger and Klarer (1991)

Moina micrura and several species in the family Bosminidae. By late summer the earlier dominant species decline and the cladoceran *Diaphanosoma birgei* becomes dominant in the estuary. In the wave zone of Lake Erie off the estuary mouth, the early summer dominants also include *Diacyclops thomasi* and bosminid species, but *Diaphanosoma birgei* does not become abundant. Bosminids, including *Bosmina longirostris*, attain by far the greatest abundance of all the cladocerans in the wave zone and the lower estuary (Krieger (1992). Haven (1991a) found a numerical dominance by rotifers and nauplii in May when the estuary mouth was open to Lake Erie, but cladocerans and nauplii were the most numerous in June after the mouth was closed by a sand barrier beach. Krieger (1985) noted that the periods when males and ovigerous females crustacean zooplankters were present, the egg ratios were greater in the estuary. This indicates that secondary productivity is higher in the estuary than in the nearshore waters of Lake Erie. He also concluded that depending on the number, timing, and severity of storm runoff events through the estuary, the seasonal abundances of zooplankters can be strongly reduced by flushing out the estuary.

Havens (1991a, l991d) examined the rotifers in Old Woman Creek estuary in 1990. He also found marked dissimilarities between the estuary and the adjacent Lake Erie. Total population numbers were 2 to 3 times greater in the estuary than in the lake. Within the estuary, rotifers were the most abundant group from early July through mid-September; while in the adjacent lake, they assumed numerical dominance only for a brief period in late July and early August. The most common rotifers in the estuary included *Polyarthra remata*, *Brachionus angularis*, *B. bidentata*, *B. calyciflorus*, and the predatory *Asplanchna* sp. The most common rotifers in the nearshore lake were *Keratella cochlearis cochlearis* and *Synchaeta kitina*.

ZOOBENTHOS

Zoobenthos are those animals living in or on the bed of a water body, be it stream, estuary, or lake (Figure 7.20). Two related groups of animals are the periphytic invertebrates, which live on the submerged surfaces of aquatic plants, and the neuston, the community of small animals such as water striders that

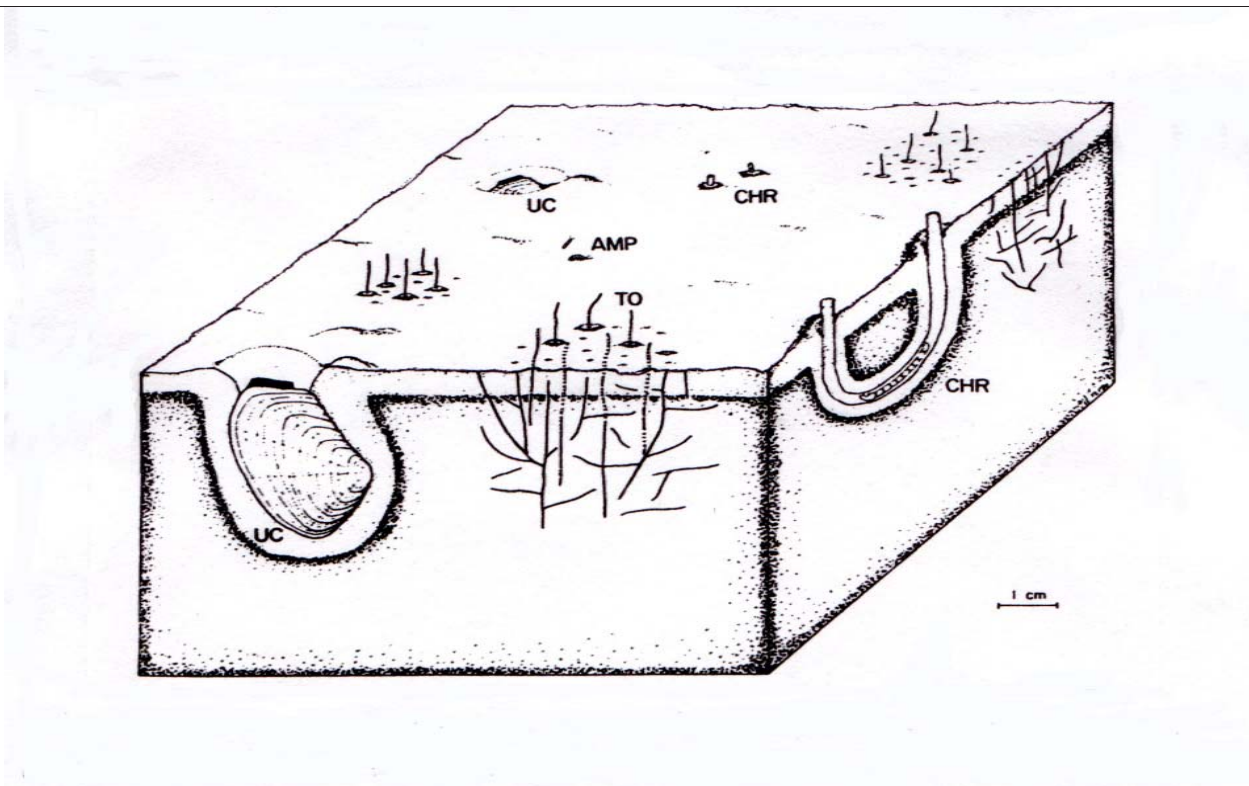


Figure 7.20. Life positions of macrobenthos in Old Woman Creek estuary (from Fisher 1982). NOTE: AMP–amphipods; CHR–chironomids, TO–tubificid oligochaetes; UC–unionid clams

TABLE 7.5. CLASSIFICATION OF BENTHIC INVERTEBRATES OF OLD WOMAN CREEK ESTUARY AND WATERSHED AND THE ADJACENT NEARSHORE WATERS OF LAKE ERIE

KINGDOM PROTISTA (PROTOZOA)

PHYLUM SARCOMASTIGOPHORA
- Subphylum Mastigophora
  - Class Dinoflagellata
  - Class Phytomastigophora
  - Class Euglenea
  - Class Zoomastigophora
- Subphylum Sarcodina
  - Class Lobosa
  - Class Filosa
  - Class Granuloreticulosa
  - Class Heliozoa

PHYLUM CILIOPHORA
- Class Kinetofragminophora
- Class Oligohymenophora
- Class Polyhymenophora

KINGDOM ANIMALIA

PHYLUM PORIFERA
- Class Demospongiae (horny sponges)

PHYLUM CNIDARIA
- Class Hydozoa (hydras)

PHYLUM PLATYHELMINTHES
- Class Turbellaria (flatworms)

PHYLUM GASTROTRICHA

PHYLUM ROTIFERA (rotifers)

PHYLUM NEMATODA (roundworms)

PHYLUM MOLLUSCA
- Class Gastropoda (snails)
- Class Bivalvia (clams)

PHYLUM ANNELIDA
- Class Hirudinea (leeches)
- Class Oligochaeta (segmented worms)

PHYLUM ARTHROPODA
- Class Arachnida (spiders & water mites)
- Class Crustacea
  - Subclass Branchiopoda
    - Order Cladocera (water fleas)
  - Subclass Ostracoda (seed shrimp)
  - Subclass Copepoda (water-hoppers)
    - Order Harpacticoida
    - Order Cyclopoida
  - Subclass Branchiura (fish lice)
  - Subclass Malacostraca
    - Order Isopoda (sow bugs)
    - Order Amphipoda (scuds)
    - Order Decapoda (crayfishes)
- Class Insecta
  - Order Collembola (springtails)
  - Order Ephemeroptera (mayflies)
  - Order Odonata (damselflies & dragonflies)
  - Order Plecoptera (stoneflies)
  - Order Hemiptera (true bugs)
  - Order Neuroptera (nerve-wing insects)
  - Order Coleoptera (beetles)
  - Order Diptera (true flies)
  - Order Trichoptera (caddisflies)
  - Order Leptopitera (butterflies & moths)

PHYLUM TARDIGRADA (water bears)

PHYLUM BRYOZOA (bryozoans)

live in association with the surface film of water bodies. Because the benthic invertebrate community represents a major food resource for fishes, impacts the plankton community through various feeding activities, participates in the decompositional pathways, and in turn is influenced by the presence of hydrophyte beds, this community is a major link in the overall ecology of the Old Woman Creek estuary. A zoobenthos study was undertaken by Krieger and Klarer (1992,1995) with two objectives: (1) to determine the relative species richness of benthic and periphytic invertebrates in open water and in aquatic plant beds within the estuary and (2) to compare the benthic community of the estuary with that of the upland creek and the adjacent nearshore of Lake Erie. The results of their investigations are summarized in the following sections.

Community Structure and Species Richness

Altogether 144 taxa of benthic invertebrates (Table 7.5) were identified from Ekman dredge and 7.5 cm diameter core samples of sediment obtained throughout the estuary as well as from leaves, stems and tubers of aquatic plants. Samples were taken approximately every two months for a period of one year. Of the nine phyla found in the estuary, 38% were insects, 22% were crustaceans, and 20% were oligochaete worms. The number of taxa found in samples taken within the American lotus beds (*Nelumbo lutea*) exceeded the number of taxa present in open water samples by about 1.5 times at the end of the growing season. Invertebrate densities on lotus stems were somewhat less than 20,000 individuals/m^2, whereas sediments typically had 100,000 or more individuals/m^2.

The most widespread species was the naidid worm *Nais variabilis*, which was found both in the sediment and on lotus plants. Immature tubificid worms were widespread throughout the estuary sediments, but were not found on plant surfaces. Although never abundant, turbellarian flatworms were widespread in the sediments and on plants. The overwintering stage of bryozoans (statoblast) was very abundant in many samples as was the ephippium capsule of cladocerans. The cladoceran *Ilyocryptus sordidus* was widely distributed and abundant during the fall and spring, but infrequent in the winter. Nematode roundworms were found in most habitats, at times in considerable abundance.

Among the insects, ceratopogonid flies were the most widespread in sediments, but not usually very abundant. The chironomid *Glyptotendipes* sp. occurred in sediments and on plants, but only in the fall and winter; whereas, *Tanytarsus* sp. was widespread in sediments mainly in the winter and spring. Corixid water boatmen were common in all habitats during the summer and fall, but absent in winter and spring. Dragonfly and damselfly nymphs were found throughout the estuary, but in low numbers. Young nymphs of capniid stoneflies were particularly common in the open water sediments and in the flooded creek channel comprising the upstream end of the estuary.

Other relatively common taxa that were restricted entirely or primarily to particular benthic habitats include all the snails—with the exception of the large Japanese snail (*Cipangopaludina japonica*) which always associate with aquatic plants. Only two live zebra mussels (*Dreissena polymorpha*) were collected, one in a sediment sample and the other on a lotus leaf, and only in the fall. Krieger and Klarer (1992) speculated that this may indicate that they do not survive over winter in the shallow habitat of the estuary. Unionid clams, although widespread, were sparse and restricted to the sediments.

Three relatively rare insects, the microcaddisfly *Agraylea* sp. and two beetle larvae (a chrysomelid and a scirtid), were found only in the sediments of lotus beds. These taxa typically live on or near vascular hydrophytes. *Agraylea* feeds on attached filamentous algae; chrysomelid larvae pierce the lotus plant to obtain air directly from the inside air spaces (lacunae); and scirtid marsh beetle larvae typically remain just below the surface film and feed on decaying leaves and other vegetation. The epiphytic invertebrate community living on a lotus stem in October consisted of six taxa: the chironomid larvae *Glyptotendipes* sp. (9,944/m^2) and *Cricotopus* sp. (5,136/m^2); naidid oligochaetes *Nais variabilis* (1,964/m^2), *Nais pardalis* (927/m^2), and *Dero nivea* (55/m^2); and ceratopogonid fly larvae (55/m^2).

Seasonally, the neuston comprises a highly visible component of the Old Woman Creek estuary invertebrate fauna. Krieger and Klarer (1992) found large aggregations of gyrinid and hydrophylid beetles, as well as corixid water boatmen, in the late summer and autumn.

Because of seasonal life cycles, several benthic taxa are only present or especially abundant during a particular season. Among the oligochaete worms, several species of *Pristina* were found only in the fall, whereas two species of *Vejdovskyella* were present only in the spring. Likewise, leeches were only collected in the fall and tardigrade water bears were only abundant during the winter and spring. Some midges were also seasonal: *Dicrotendipes* sp. was found only in the fall, *Glyptotendipes* sp. in the fall and winter, and *Hydrobaenus* sp. in the winter.

On an annual basis, the benthic community of Old Woman Creek estuary is dominated numerically by nematodes, tubificid and naidid worms, tardigrades, ceratopogonids, cladocerans (particularly *Ilyocryptus sordidus*), and chironomids. Overall, the plant beds contained a greater species richness than the open water areas. Essentially, the sediment within the plant beds contained almost all of the taxa found in the open water sediment as well as several species associated specifically with hydrophytes.

Comparison of Estuary, Creek, and Lake Communities

Krieger and Klarer (1992) concluded that the benthic community of Old Woman Creek estuary is distinct from the benthic communities of the upland creek and adjacent Lake Erie. They found the presence of an ecotone (a narrow and fairly sharply defined transition zone between two communities) at the upper end of the estuary where the zone is restricted to the flooded Old Woman Creek channel. In this channel the larvae of the riffle beetle *Dubiraphis* sp., which was characteristic of the upland creek bed, were present throughout the year in relatively small numbers, whereas, these larvae were essentially absent in the remainder of the estuary. Likewise the early instars of capniid stoneflies were frequent in the upstream pools and the flooded upper channel of the estuary, but were rare elsewhere in the estuary. *Ilyocryptus sordidus*, which was dominant in the open estuary, was present in low numbers in the upper end of the estuary and was usually absent in the upland creek bed.

Correspondingly, the nearshore wave zone of Lake Erie along the barrier beach at the mouth of Old Woman Creek estuary possesses a distinct macroinvertebrate community. Here, the shifting sands create a harsh environment resulting in a smaller abundance of the same groups which dominate the more offshore, less sandy, softer sediments of the nearshore zone of the lake. The dominant members of the lake community include the tubificid oligochaetes, especially *Limnodrillus* spp.; chironomid larvae, primarily *Procladius* sp., *Chironomus* spp., and *Cryptochironomus* sp.; sphaeriidae clams; ostracods; and nematodes. Each of these taxa were at least occasionally found in the estuary, except sphaeriidae clams which were absent.

Ecological and Tropic Interactions

Krieger and Klarer (1992) also tested the hypothesis that differences in the benthic invertebrate community were the result of differences in water depth and thus the frequency of subaerial exposure of the estuary bed (i.e. water level lowered to the point where sediments were exposed to the air). Their study showed no evidence of differences in community structure along the depth gradient in the estuary, even though some of the sampling sites were exposed up to 31% of the time. However, during these periods of dewatering the sediments appeared to remain moist. Despite occasional freezing at the sediment surface in winter, the invertebrate community apparently survived the conditions without demonstrable effect. The investigators speculated that the invertebrate community may have been adversely affected by exposure, but recovery via recolonization or hatching of eggs or cysts may have been too rapid to be detected.

Also, physical and chemical differences in the water column and sediments appear to have little influence on the benthic community structure in the broad expanse of the estuary; physiochemical variations never reached limits to survival and reproduction of the major invertebrates in the open estuary. Strong water currents during periods of storm runoff, however, may be responsible for the ecotonal nature of the flooded creek channel comprising the upper end of the estuary. Under these conditions, invertebrates are most likely washed from their typical stream habitats and deposited downstream where the water velocity is lower.

The interactions of the many benthic invertebrate taxa with each other and the vertebrates, aquatic plants, and decompositional communities constitute an important aspect of the Old Woman Creek estuary ecology. Knowledge of the seasonal distribution and abundance of these taxa is an essential foundation for understanding these interactions. The study by Krieger and Klarer (1992) suggests that a complex food web exists in the estuary. However, few benthic invertebrates appear highly specialized in their food habits. Most carnivores feed on a variety of prey, detritivores often ingest microinvertebrates and algae along with detritus, and many invertebrate “scrapers” and “grazers” are omnivores, nonselectively ingesting whatever is present on the substrate and unable to escape. Table 7.6 lists the trophic categories of the major benthic invertebrates identified from Old Woman Creek estuary. Unfortunately, knowledge of invertebrate energetics and materials cycling in Great Lakes estuaries and coastal wetlands is limited and determining the exact pathways of energy and material flow through the food web of Old Woman Creek estuary can only be ascertained by further observations.

Fish and Reptile Ecology of the Estuary

Fish Community

The diversity of species present in Old Woman Creek reflects typical fish populations of estuarine areas along Lake Erie’s southern shore. The importance of these coastal areas for the production of commercial, recreational, and forage fishes has been documented by Trautman (1957,1981) and Hartman (1973). About 40 species of Lake Erie fish need “marsh-like” habitat to spawn and raise young (Johnson 1989). Hoffman (1985) found that the large numbers of young of the year (YOY) and juvenile fishes captured in the estuary with test nets reflect the importance of the Old Woman Creek estuary as a nursery and spawning area.

TABLE 7.6. TROPHIC CATEGORIES OF BENTHIC INVERTEBRATES FOUND IN OLD WOMAN CREEK ESTUARY

Carnivores	Detritivores	Herbivores	Omnivores	Parasites
Ciliophora	Oligochaeta: *Nais*	Ciliophora	Rotifera	Dtera: *Parachironomus*
Turbellaria	Tubificdae	Naididae	Bryozoa	Hirudiea: *Helobdella* &
Naididae:*Chaetogaster*	Hirudinea: Glossiphoniidae	Tubificidae	Coleoptera:	*Plaobdella*
Hirudinea: Glossiphoniidae	Turbellaria	Bryozoa	Elmidae	Hdrachnidia larvae
Bryozoa	Bryozoa	Nematoda	Hydrophillidae: *Tropisternus*	
Nematoda	Nematoda	Rotifera	Scirtidae: *Cyphon*	
Rotifera: *Asplanchna*	Coleoptera:	Tardigrada	Diptera:	
Coleptera:	Scirtidae: *Cyphon*	Coleoptera:	Ephydridae	
Dytiscidae	Hydrophilidae: *Helophorus*	Chrysomelidae	Chironomidae:	
Gyrinidae	Halipiidae: *Peltodytes* adults	Hydrophillidae: *Loccobius* &	*Chironomus*	
Tropisternus larvae	Diptera:	*Tropisternus* adults	*Cladoplema*	
Halipiidae: *Peltodytes* adults	Ephydridae	Scirtidae: *Cyphon*	*Dicrotendipes*	
Diptera:	Tipulidae	Halipiidae: *Peltodytes* adults	*Endochironomus*	
Ceratopogonidae	Chironomidae:	Diptera:	*Glyptotendipes*	
Chaoboridae	*Chironomus*	Ephydridae	*Parachironomus*	
Ephydridae	*Endochironomus*	Tipulidae	*Polypedilum*	
Chironomidae:	*Glyptotendipes*	Chironomidae:	*Stictochironomus*	
Cryptochironomus	*Polypedilim*	*Endochironomus*	*Tribelos*	
Parachironomus	*Stictochironomus*	*Glyptotendipes*	*Tanytarsini*	
Polypedilum	*Tribelos*	Corixidae: *Sigara*	*Hydrobaenus*	
Coelotanypus	Plecoptera: Capniidae	Trichoptera: *Agraylea*	*Procladius*	
Procladius	Amphipoda		*Tanypus*	
Tanypus	Cladocera: Chydoridae &		*Heterotrissocladius*?	
Hemiptera: *Belostoma*	Macrothricidae		Ephemeroptera	
Corixidae: *Trichocorixa*	Copepoda: Cyclopoida &		Corixidae:	
Neuroptera: *Sialis*	Harpacticoida		young *Trichocorixa*	
Odonata	Isopoda		*Sigara*	
Copepoda: Cyclopoida	Ostracoda		Trichoptera, *Agraylea*	
Hydrachnidia:	Gastropoda		Amphipoda	
deutonymphs, adults	Bivalvia		Cladocera	
			Copepoda: Calanoida,	
			Cyclopoida &	
			Harpacticoida?	
			Isopoda	
			Ostracoda	
			Gastropoda	
			Bivalvia	

Data Sources: Balcer et al. (1984), Merritt and Cummins (1984), Pennak (1989), Thorp and Covich (1991), Krieger and Klarer (1992)

Environmental changes, both natural and man-made have resulted in changes in fish species occurrence over the past decade. Siltation, turbidity, wave action, changing water levels, toxic substances, and increased development have all contributed to the demise of coastal marshes along Lake Erie (Raphael and Jaworski 1978). Likewise, Old Woman Creek has experienced some of these changes—particularly during high water years—which were especially detrimental to emergent plants. Agricultural activities throughout the watershed and removal of upland forests have contributed to the increased turbidity and siltation in streams, resulting in unfavorable conditions for fishes that require clear water and clean sand or gravel substrates for spawning (Trautman l957).

Northern pike populations of Old Woman Creek in the 1950s were productive enough to permit the Ohio Division of Wildlife to remove some for stocking in other areas of Ohio. Old Woman Creek was reportedly one of the most productive fishing spots for crappie and largemouth bass as well as northern pike along Lake Erie (Miller 1957). Although the more tolerant crappie and largemouth bass still are quite numerous, few northern pike have been captured in recent times. Seining has produced no northern pike. However, electroshocking in the 1984 season produced two juvenile pike, and one adult was captured in a gill net.

Ohio Division of Wildlife surveys from 1970-1980 recorded 4 pike captured in fyke nets set in Old Woman Creek. Although the entire Lake Erie northern pike population is low (Trautman 1981b), the only obvious reason for such a drastic decline in abundance over 30 years seems to be loss of appropriate habitat. Old Woman Creek was historically in the “prairie” type marshlands of Ohio, and its once heavily vegetated waters offered ideal spawning and rearing habitat that attracted great numbers of pike during their early spring spawning runs. The pike is not the only species of fish to succumb to habitat changes in Old Woman Creek. Hoffman (1985) reported abundant populations of bowfin, smallmouth bass, buffalofish, longnose gar, and Northern fathead minnows. Recent sampling has not produced any buffalofish and very few gar, bowfin and fathead minnows. The low numbers of these species suggest some type of environmental change not favorable to these species.

Johnson (1989) suggested that natural wetlands cover such a relatively small area along the Lake Erie coast and are so readily destroyed or degraded, that controlled marshes may represent the last high quality coastal marsh resource remaining on the lake. Thus, the fate of northern pike, and other species sensitive to environmental changes is tenuous. From 1970-1980, 327 black bullheads and 45 brown bullheads were captured in fyke nets set by the Division of Wildlife. Sampling conducted in Old Woman Creek by Thibault (1985) in 1983 and 1984 shows a complete reversal in the species ratio, with 111 brown bullheads captured and only 10 black bullheads recorded. Trautman (1981) found that black bullhead tend to use small, silty impoundments, while brown bullhead tend to prefer deeper waters similar to those of the Ohio River and western Lake Erie. Old Woman Creek does not follow this trend. The shallow, heavily silted, turbid waters of the estuary appear to favor the brown bullhead. Perhaps the estuary’s close proximity to Lake Erie and seasonal access may have permitted the brown bullhead to establish an abundant resident population.

The orangespotted sunfish was first taken in the tributaries of the Sandusky Bay in 1948 (Trautman 1981b). This invader from the west is becoming abundant in the marshes and small streams of southern Lake Erie due to their tolerance to high silt and turbidity. The first record for orangespotted sunfish in Old Woman Creek was in 1981, and this species of sunfish has been captured in each successive year. Numbers have increased, and the orangespot is now very common in the estuary (Hoffman 1985). Another invading species, the white perch, was first captured in Old Woman Creek estuary in July, 1980. Considerable numbers were recorded at the mouth of the estuary in the company of white bass during spawning months. YOY and 1st year white perch were numerous in late summer months. Trautman (1981) suggests that new invaders first become overly abundant, then experience a decline as the species becomes a part of the resident fish fauna.

The gizzard shad is an important forage fish in Lake Erie (Bodola 1966). The shad, while playing an important role as food for many sport and commercial species, grows to a large size so rapidly that they become unusable to predators (Scott and Crossman 1973). Gizzard shad captured from 1981-1984 in Old Woman Creek were about 95% YOY and 1st year class fishes (Hoffman 1985, Thibalt 1985). The protected, shallow waters of the estuary and the abundance of phytoplankton and algae offer a nursery situation which is very favorable for shad. Gizzard shad in the larval and juvenile stages make up the largest percentage of the diet in piscivorous fishes in Old Woman Creek estuary. During the time immediately following a major storm event large numbers of shad are killed and are carried out into the lake. Researchers have noted on several occasions that during these times, predatory fish such as the white bass, and several species of gulls congregate offshore to feed (Hoffman 1985).

Little is known about the effects of the shifting barrier beach at the mouth of the estuary on anadromous species such as trouts and salmons. Continued monitoring may show whether seasonal opening and closing of the estuary mouth hampers fish attempts to enter spawning habitat. In nearby Cranberry Creek, where the mouth remains open year around, steelhead trout and coho salmon are frequently caught by sport fishermen during spring spawning runs (Hoffman 1985).

Thibault (1985) found that the estuary of Old Woman Creek appears to have a fish fauna of its own and is probably an established environment for a number of species of fish. A gradient in environments sustains a gradient in fish species varying from more open water (lacustrine) to more flowing water (riverine) forms. Traditional Lake Erie fishes of commercial importance frequent the estuary erratically and are not a significant component of the fauna. However, these fishes episodically reproduce in the estuary or use it for a nursery.

Thoma (1999) concluded that Old Woman Creek estuary was severely impacted by sedimentation from the watershed, especially that resulting from highway construction. He found that the estuary was characterized by a fish community of pollution-tolerant taxa and non-indigenous species. The low density of the fish community was in contrast to the historic fish communities which contained significant populations of northern pike, largemouth bass, other sunfish, and native minnows.

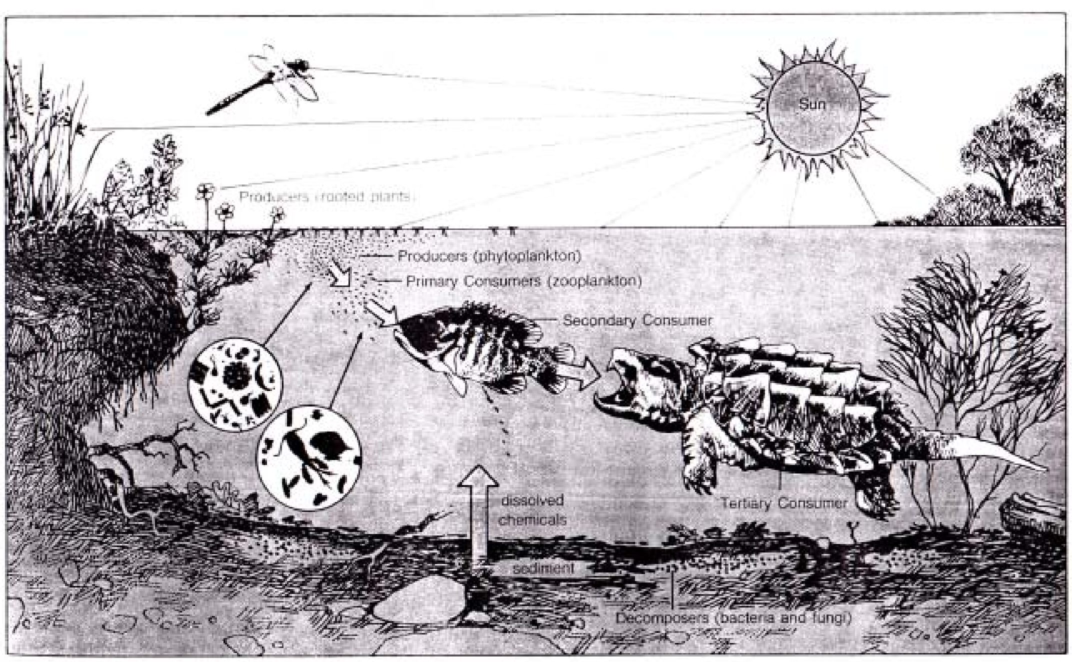


Figure 7.21. Aquatic food chain in Old Woman Creek estuary (ODNR).

Snapping Turtles

The snapping turtle (*Chelydra serpentina*) is the largest freshwater turtle in the Great Lakes region, growing to lengths of over 70 cm (average shell 28 cm long) and weights of more than 20 kg (average 5 to 16 kg). Conant and Collins (1991) describe them as "ugly both in appearance and disposition." They have a large head, heavy neck, stout legs, and a long, saw-toothed tail that are not covered by the rough, dark brown carapace (upper shell). The small, cross-shaped plastron (lower shell) allows free action of the legs and head, and is dark brown to yellow in color (Morgan 1930). Snapping turtles inhabit permanent marshes and embayments of Lake Erie and its tributary streams. Bernhardt (1985) reported them as common in Old Woman Creek estuary, particularly south of Star Island. Of 21 specimens noted in his survey (82% females), the carapace length ranged from 18 to 40 cm, with two individuals exceeding 15 kg in weight. One female was extremely pale in color and had a length of 31 cm and a weight of 11 kg (Figure 1.7).

In addition to their aquatic habitat, snapping turtles are commonly found on land near a water body or exploring adjoining fields (Morgan 1930). They rarely bask on logs as do most other freshwater turtles; in shallow water they often burrow under the mud with only their eyes and nostrils showing (Conant and Collins 1991). However, snapping turtles are good swimmers, capable of covering 3 km in several hours (Behler and King 1979). When catching food, the head darts forward, mouth often agape, and powerful jaws snap suddenly (Figure 7.21). Although their movements are normally slow, the head can strike with lightning speed. Snapping turtles are seldom ill-tempered when encountered in the water, although on land they are aggressive and sometimes vicious. Their musk-like odor is also offensive (Klots 1966). They are omnivorous and seek food both night and day. Food items include fish, reptiles, frogs, insects, crayfish, ducklings, small mammals, carrion, and large quantities of aquatic plants (Buck 1955). In winter, snapping turtles hibernate in the mud bottom of the estuary, emerging from their retreats in April.

Ecological Models

Heath (1992) constructed a conceptual model of nutrient dynamics for Old Woman Creek based on a synthesis of research investigations conducted at the Research Reserve (Figure 7.22). His model emphasizes the importance of sediment–water interactions owing to the shallowness of the estuary. Microbial activity in the water column, at the sediment–water interface, and within the sediment is considered intense because of the high temperatures resulting from the shallowness. The water column is treated without vertical structure because complete mixing is frequent, providing sediment resuspension and wide diurnal variations in dissolved oxygen at the sediment surface (Figure 5.13).

The model is designed to represent the estuary during a period of relatively low flow, as occurs after formation of the barrier beach. The model is also built on the assumption that after formation of the barrier beach biotic nutrient assimilation becomes progressively more significant during the passage of incoming nutrients through the estuary wetlands; although sedimentation may also represent a major sink for incoming nutrients. When the barrier beach is open and flow through the wetlands occurs, nutrient loss from the water column is largely due to sorption on sediment particles.

Mitsch and Reeder (1991) and Mitsch (1992b) developed a series of hierarchical models to simulate ecological processes in Old Woman Creek estuary. Figure 7.23 shows a model of the estuary with details of some of the processes in a wetland which contribute to its nutrient retention capability. Plant uptake, both by plankton and macrophytes, sedimentation, and resuspension are probably the most significant processes involved in the wetland retaining and releasing phosphorus. This conceptual model was developed into a simulation model based on knowledge of the cycling of phosphorus and energy in wetland ecosystems. Unique to this wetland model is the interaction of Lake Erie with the wetland. The model was divided into three submodels for simulation purposes.

A hydrology submodel of the simulation model is designed to depict the hydrologic budget of Old Woman Creek wetland with the only stated variable for this submodel being the volume of water in the estuary. Factors affecting the volume of water in the marsh include rainfall, watershed inflow, evapotranspiration, and exchange with Lake Erie. The availability of inflow data, fairly good data on evaporation, and knowledge of the hydrologic forcing functions in the wetland allowed the development of an accurate hydrologic budget and model. An important part of the hydrodynamics is the timing of an ephemeral barrier beach on the wetland outflow.

A primary productivity submodel includes the state variables macrophyte biomass and plankton biomass. These are both a function of sunlight, with the major losses being respiration and sedimentation. The productivity submodel is linked to the hydrology submodel in two ways. First, plankton are exported to Lake Erie when water from the wetland flows into the lake and the beach is open. This assumption is consistent with the field data. Second, macrophytes are assumed to be more abundant when water levels are lower, and less abundant when water levels are higher. This is based on observations of other Lake Erie coastal marshes (Herdendorf 1987). Field measurements of gross primary productivity as measured in Old Woman Creek estuary were in general agreement with model simulations. Using chlorophyll *a* as a calibration variable, the model and field data were found to be in agreement (within one standard deviation) 78% of the time. Given the differences in the two field measurements and the variability of energy/chlorophyll ratios in aquatic systems (Vollenweider 1974), the model accurately predicted seasonal patterns of productivity and biomass.

A phosphorus submodel was coupled with both the hydrology and primary productivity submodels and is incapable of running simulations without input from these submodels. This submodel utilizes one phosphorus storage in the waters of the wetland and another in the sediments, with linear pathways between the two. The phosphorus submodel includes a sedimentation pathway as defined for shallow lakes by Henderson-Sellers (1984) with an average settling velocity of 0.03 m d^{-1}. Calibration was done by varying the resuspension coefficient until the model predicted phosphorus concentration results similar to field data.

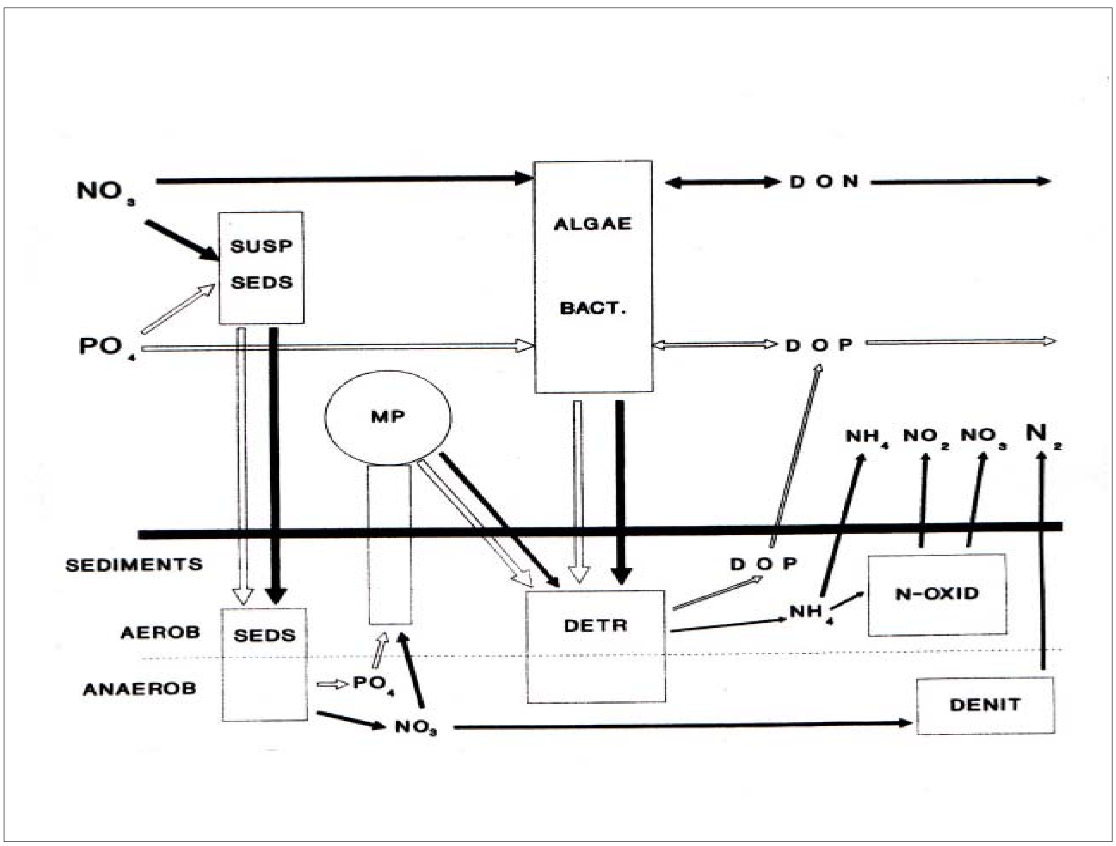


Figure 7.22. Conceptual model of nutrient dynamics in Old Woman Creek estuary.

NOTE: Nitrogen flux in solid arrows; phosphorous flux in open arrows; particulate quantities in boxes; dissolved quantities unboxed; SUSP SED—suspended sediment; SEDS—sediments, aerobic sediments above dashed line and anaerobic sediments below; water column above heavy solid line; MP—rooted macrophytes; DETR—detritus; N–OXID—nitrogen oxidizing bacteria; DENIT—denitrifying bacteria (Heath 1992).

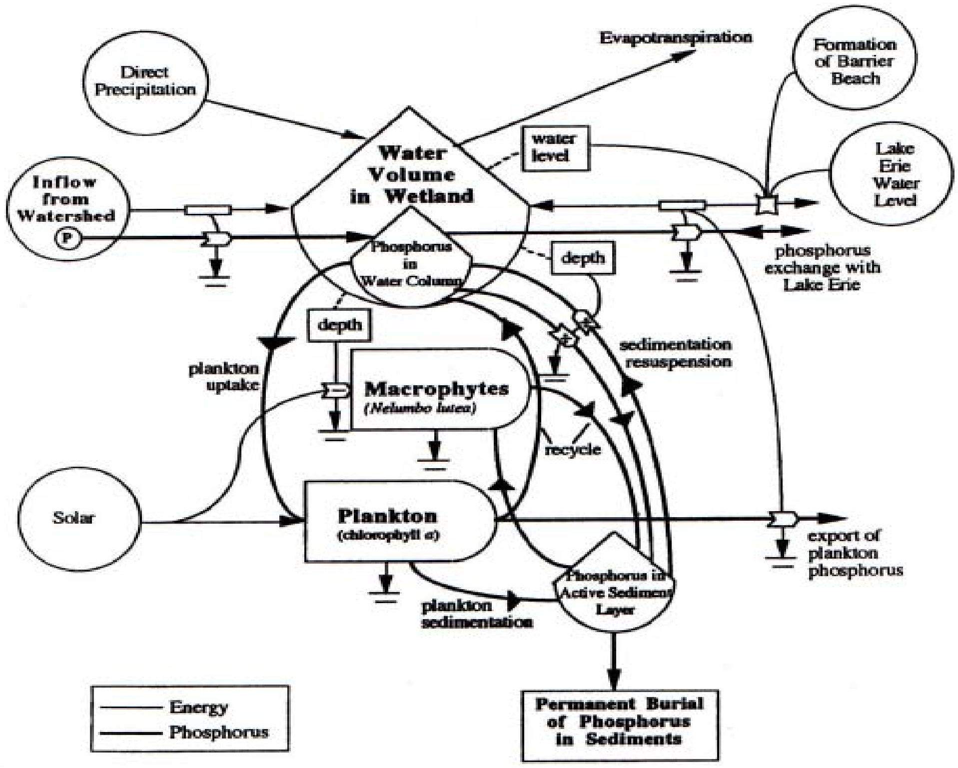


Figure 7.23. Conceptual model of ecological processes in Old Woman Creek estuary (Mitsch and Reeder 1991).

Hydrology, productivity, and phosphorus field data enabled model calibration and preliminary estimations to be made of the role of phosphorus sedimentation and phosphorus resuspension in the shallow estuary. Simulations show high levels of sedimentation in the early spring, with resuspension exceeding sedimentation through the remainder of the year. This excess of phosphorus resuspension over sedimentation in the model simulations is surprising at first, but the productivity estimates throughout the year clearly illustrate that there is insufficient phosphorus in the inflow to support the high level of productivity and the generally high phosphorus concentrations experienced in the wetland from May through November.

The model also predicts the total phosphorus sedimentation rate, including contributions from plankton and macrophytes. Sedimentation rates as high as 40 mg P $m^{-2}d^{-1}$ are simulated for the spring, while the rate for the remainder of the year, when very little allochthonous inflows are experienced, is around 10 mg P $m^{-2}d^{-1}$. The simulated rates of sedimentation and resuspension translate to a total net sedimentation of 0.8 g P m^{-2} for the 9-month study period. This contrasts to an estimated annual retention of 5-7 g P m^{-2} predicted a few years earlier using a simple empirical model (Mitsch 1989a). Because the model is based on the year 1988 which had a significant drought, the net sedimentation rate can be expected to be well below average. Thus, it is not unreasonable to suggest that the model predicted less than 20% of normal sedimentation because the calibration year was a period of extreme drought and the model was based on nine months instead of twelve. Subsequent simulations (Mitsch and Reeder 1991) show that higher inflows for the same 9-month period lead to proportionately higher net retention of phosphorus, approximately 1.3 to 3.3 g P m^{-2}, respectively, for normal and wet years.