1.1 Impact of Invasive Aquatic Plants on Aquatic Biology

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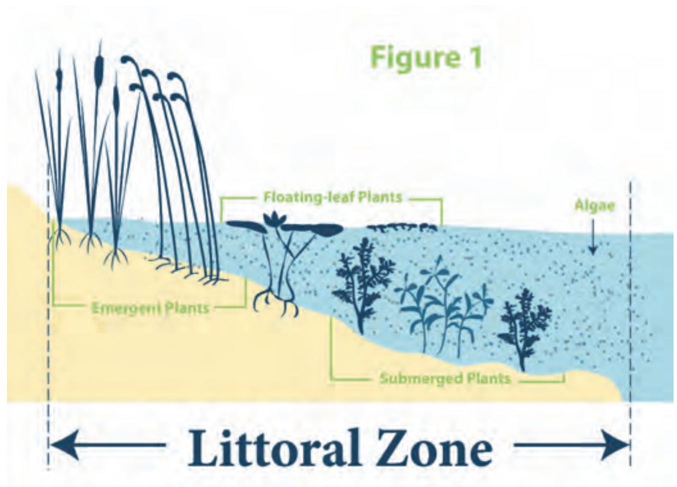
Introduction

Aquatic plants play an important role in aquatic systems worldwide because they provide food and habitat to fish, wildlife and aquatic organisms. Plants stabilize sediments, improve water clarity and add diversity to the shallow areas of lakes. Unfortunately, nonnative plants that are introduced to new habitats often become a nuisance by hindering human uses of water and threatening the structure and function of diverse native aquatic ecosystems. Significant resources are often expended to manage infestations of aquatic weeds because unchecked growth of these invasive species often interferes with use of the water, increases the risk of flooding and results in conditions that threaten public health.

Types of aquatic plants

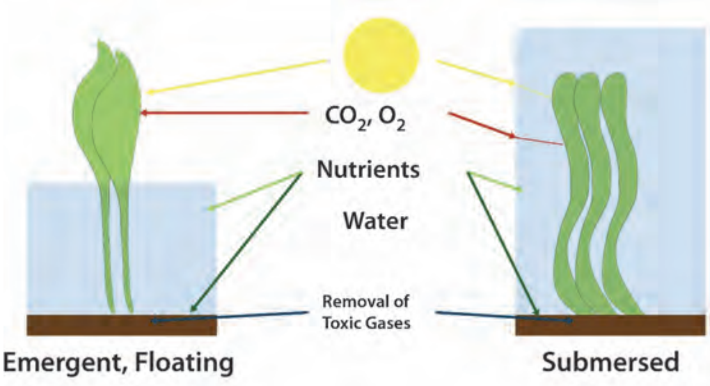
Aquatic plants grow partially or completely in water. Macrophytic plants are large enough to be seen with the naked eye (as compared to phytoplankton, which are tiny and can only be identified with a microscope) and are found in the shallow zones of lakes or rivers. This shallow zone is called the littoral zone and is the area where sufficient light penetrates to the bottom to support the growth of plants. Plants that grow in littoral zones are divided into three groups. Emergent plants inhabit the shallowest water and are rooted in the sediment with their leaves extending above the water's surface. Representative species of emergent plants include bulrush (*Scirpus* sp., *Schoenoplectus* sp.), cattail (*Typha* sp.) and arrowhead (*Sagittaria* sp.). Floating-leaved plants grow at intermediate depths. Some floating-leaved species are rooted in the sediment, but others are free-floating with roots that hang unanchored in the water column. The leaves of floating-leaved plants float more or less flat on the surface of the water. Waterlily (*Nymphaea* sp.) and spatterdock (*Nuphar advena*) are floating-leaved species, whereas waterhyacinth (Section 2.11) and waterlettuce (Section 2.12) are free-floating plants. Submersed plants are rooted in the sediment and inhabit the deepest fringe of the littoral zone where light penetration is sufficient to support growth of plants. Submersed plants grow up through the water column and the growth of most submersed species occurs entirely within the water column, with no plant parts emerging from the water. Submersed species include invasive plants such as hydrilla (Section 2.2), Eurasian watermilfoil (Section 2.3) curlyleaf pondweed (Section 2.4) and egeria (Section 2.5) along with native plants such as vallisneria (*Vallisneria americana*), coontail (*Ceratophyllum demersum*) and others.



Algae (Section 2.18) also grow in lakes and provide the basis of the aquatic food chain. The smallest algae are called phytoplankton and are microscopic cells that grow suspended in the water column throughout the lake. Dense growth of phytoplankton may make water appear green, but even the "cleanest" lake, with no green coloration, has phytoplankton suspended in the water. Filamentous algae grow as chains of cells and may form large strings or mats. Some filamentous algae are free-floating and grow suspended in the water column, but other species grow attached to plants or the bottom of the lake. Macroscopic or macrophytic algae are large green organisms that look like submersed plants, but are actually algae (Section 2.15).

What aquatic plants need

Plants have simple needs in order to grow and thrive – they require carbon dioxide, oxygen, nutrients, water and light. Plants use light energy, water and carbon dioxide to synthesize carbohydrates and release oxygen into the environment during photosynthesis. Animals use both the carbohydrates and oxygen produced by plants during photosynthesis to survive, so without plants there would be no animal life. The nutrients required in the greatest quantity by plants are nitrogen and phosphorus, but a dozen or more other minerals are also needed to support plant growth. Plant cells use oxygen in the process of respiration just like animal cells, but this is often forgotten since plants produce more oxygen than they need for their own use.



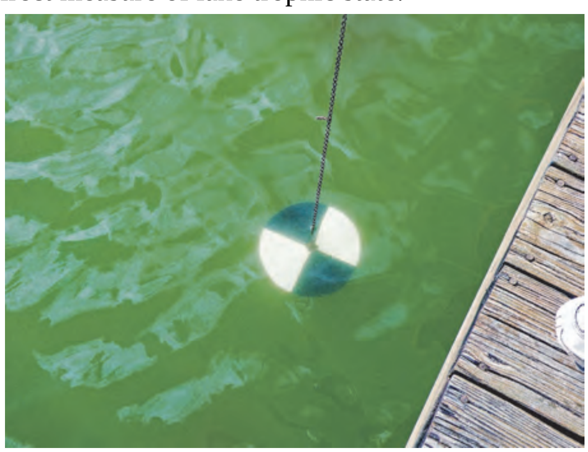
Aquatic plants inhabit an environment very favorable in one respect – most terrestrial plants must find sufficient water to survive. Aquatic plants are literally bathed in water, one of the primary requirements for plant growth. Since aquatic sediments are typically high in nitrogen and phosphorus, life might appear idyllic for aquatic plants. Once the leaves of emergent and floating–leaved plants rise above the water surface, they have a ready supply of carbon dioxide, oxygen and light. In addition, the leaves may act as a conduit for the ready disposal of toxic gases like methane and sulfur dioxide that are produced in the sediments surrounding plant roots. Given these factors, it is no surprise that emergent plants in fertile marshes are among the most productive ecosystems in the world.

Alas, life is not as easy for submersed plants. While submersed plants have easy access to the same pool of nutrients from the water and the sediment, the availability of light and carbon dioxide is significantly reduced since most submersed plants live completely under the water. Light must penetrate through the water column to reach submersed plants; therefore, much less light energy is available to them. Also, carbon dioxide must be extracted from the water, an environment in which carbon dioxide is present in much lower concentrations and diffuses much more slowly than in air. As a result, submersed plants are much less productive and produce less biomass than emergent and floating plants and the primary factors limiting their growth are the availability of light and carbon dioxide. Some highly productive plants have developed the means to increase their access to light and carbon dioxide. For example, species such as hydrilla form dense floating mats or canopies on the surface of the water, which allows them to capture light energy that is less available near the bottom of the water column. These productive (and often invasive) aquatic plants form dense colonies that interfere with human uses of the littoral areas, increase flooding risk and shade out other plants – including most native species – that do not form canopies.

Lake ecology

Trophic state

Trophic state describes the overall productivity (amount of plants or algae) of a lake, which has implications for the biological, chemical and physical conditions of the lake. For example, aquatic animals use plants as a food source, so unproductive lakes do not support large populations of zooplankton, invertebrates, fish, birds, snakes and other animals. The trophic state of a lake is directly tied to the overall algal productivity of the lake and ranges from very unproductive to highly productive. Because phytoplankton typically control lake productivity, factors that increase algal productivity also increase the trophic state of the lake. Algal biomass in a lake is estimated by measuring the concentration of chlorophyll in the water; hence, lake chlorophyll concentration is a direct measure of lake trophic state.



Chlorophyll is directly related to phosphorus concentration in the lake, so phosphorus is also considered a direct measure of lake trophic state. Lake transparency is the most widely measured characteristic to determine trophic state because growth of algae increases water turbidity – high algal growth reduces water clarity, which suggests high productivity. Trophic state can be measured with a Secchi disk because most turbidity in lakes is caused by suspended algae. Since increased algal growth makes the water less transparent, Secchi disk depth is a measure of lake trophic state. Chlorophyll, phosphorus and Secchi disk depth are measured in different units. The Trophic State Index (TSI) employs equations that allow users to develop a single uniform number for trophic state based on any one of the three factors alone or on the average of all three factors (chlorophyll, total phosphorus or Secchi disk depth). This tool is useful to compare trophic state data collected by differing methods and has empowered hundreds of lay monitors to collect trophic state data using only a Secchi disk to estimate water clarity.

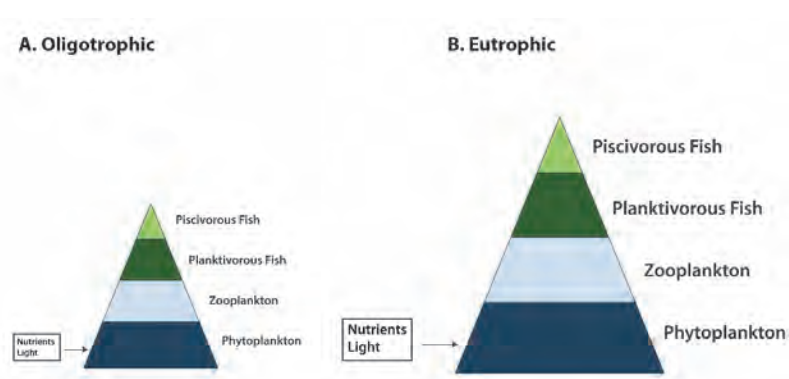
Four terms are commonly used to describe lake trophic state. Oligotrophic lakes are unproductive with low nutrients (phosphorus < 15 µg/L) and low algal productivity (chlorophyll < 3 µg/L). Transparency, as measured by the Secchi disk method, is greater than 13 feet. Oligotrophic lakes are typically well-oxygenated and often support cold-water fisheries in the northern US. Mesotrophic lakes are moderately productive, with intermediate levels of chlorophyll, nutrients and water clarity. Mesotrophic lakes may support abundant populations of rooted aquatic plants and often have cool-water fisheries. Eutrophic lakes are highly productive, with high levels of phosphorus and chlorophyll. Water clarity is low and generally ranges from 3 to 8 feet as measured by the Secchi disk method. Eutrophic lakes may support bass fisheries but rarely have productive open-water fisheries. Hypereutrophic lakes have very high phosphorus and chlorophyll levels and water clarity is usually less than 3 feet. In most cases, hypereutrophic lakes are the result of nutrient loading from human activity in the watershed. Algal growth dominates in the lake and few or no rooted submersed plants are present.

Trophic state	Chlorophyll concentration (µg/L)	Total phosphorus concentration (µg/L)	Water clarity (by Secchi disk, in feet)	Trophic State Index	Description
Oligotrophic	< 3	< 15	> 13	< 30	Very low productivity Clear water Well oxygenated Few plants and animals
Mesotrophic	3-7	15-25	8-13	40-50	Low to medium productivity Moderately clear water Abundant plant growth
Eutrophic	7-40	25-100	3-8	50-60	Medium to high productivity Fair water clarity Dense plant growth
Hypereutrophic	> 40	> 100	< 3	> 70	Very high productivity Poor water clarity Limited submersed plant growth, algae dominate

Studies of sediment cores from across the US have verified that many lakes were naturally mesotrophic or eutrophic before Europeans settled in the US, which conflicts with the assumption that all "pristine" lakes are oligotrophic. The nutrient status or trophic state of lakes that are unaffected by human activity is a function of the watershed and its geology. That being said, human activity that causes nutrient runoff into lakes can shift a lake to a higher trophic state, which alters many biological and chemical attributes of the lake. There are many examples of pollution-degraded lakes, but the water quality of many lakes has improved since the passage of the first Clean Water Act in 1972 and these lakes are returning to their historic water quality levels due to efforts to restore our waterways.

Productivity in lakes

As mentioned above, algae and macrophytic plants are the basis for lake productivity. Plants take up nutrients, water and carbon dioxide from the environment and use light energy to produce carbohydrates and sugars, with oxygen as a byproduct. Herbivores such as crustaceans and insects consume aquatic plants and use energy from the plants to grow. Forage fish such as minnows and bluegill consume these herbivores and use energy from the herbivores to grow. Fish-eating fish such as trout, bass, pike and walleye



eat these forage fish and use energy from the forage species to grow (Section 1.2). Because each level of this feeding system is based on the energy of the level below it, this system is often described as a food pyramid. Oligotrophic lakes with few nutrients and little plant production have small pyramids, whereas eutrophic lakes with much higher nutrient concentrations, more total plant growth (algae and rooted plants) and more fish have larger pyramids. This relationship has been recognized by the aquaculture industry and fertilizer is frequently added to production ponds to increase fisheries productivity. However, changes in water quality can increase populations of undesirable fish along with populations of more desirable species in reservoirs and in natural systems.

Food chains in lakes

A food chain is a depiction of what various organisms in an ecosystem consume. Food chains begin with algae and plants, which are followed by herbivores, small forage fish and finally by the top-level predator. There may be a hundred species in a lake, so the food chain is often simplified to include only the dominant species. Phytoplankton form the base of the food chain in a typical pelagic (open-water) zone. Phytoplankton are consumed by zooplankton (small crustaceans) that are suspended in the water. Zooplankton are in turn eaten by smaller fish such as yellow perch. Yellow perch are then consumed by the top predator such as walleye.

The food chain in the littoral zone is different. Some algae are present – both as phytoplankton and as algae growing on plant surfaces – but much of the food is derived from macrophytic plants. Most macrophytes are consumed only after they have died and partially decomposed into detritus. Detritus is eaten primarily by aquatic insects, invertebrates and larger crustaceans. These detritivores, which live on or near the lake bottom, are in turn consumed by the dominant littoral forage fish such as bluegill sunfish. Lastly, forage fish are consumed by the top predator such as largemouth bass.

Littoral and cold-water pelagic zone food chains are often isolated from each other and almost function as two separate ecosystems within the same lake. The substantial changes caused by shifts between these food chains are exemplified by the history of Lake St. Clair in Michigan. Lake St. Clair only looks small compared to the Great Lakes it lays between – Lakes Huron and Erie. In fact, it is a 430 square mile lake with a maximum depth of 30 feet, although over 90% of the lake is 12 feet deep or less. This shallow lake was very turbid before 1970, with a Secchi disk transparency of only 4 feet. Rooted plants grew in about 20% of the lake and Lake St. Clair was home to a world-class commercial and recreational open-water walleye and yellow perch fishery. Lake St. Clair was invaded in the 1980s by the zebra mussel, an invasive bivalve (clam) that filters water by consuming suspended phytoplankton and the nutrients associated with them. Zebra mussels filtered the water of Lake St. Clair so effectively that water transparency more than doubled a few years after their invasion. Rooted plants expanded to almost 80% of the lake due to increased light penetration and the fishery completely changed. Walleye and yellow perch can still be found, but the former open-water fishery is now used largely for recreational angling for largemouth bass, a typical littoral zone predator.

Aquatic plant communities

Native aquatic plant species tend to separate into depth zone bands (referred to as depth zonation), with a mix of species found in each depth zone. Submersed plants may be found in water as deep as 30 feet or more in oligotrophic lakes and distinct bands of vegetation are visible to the shoreline. Plants in oligotrophic lakes are adapted to low levels of nutrients and carbon dioxide. Light penetrates easily to 30 feet or more and light levels are not limiting, but plants are typically very short. Submersed aquatic mosses also grow at water depths of up to 200 feet in Crater Lake in Oregon. Plant diversity is often relatively low and native plants in oligotrophic lakes rarely form populations that are substantial enough to cause problems.

Depth zonation in mesotrophic lakes is likewise pronounced, with submersed plants growing in water as deep as 15 to 20 feet. Submersed plants may grow to reach the surface of the water, but this growth is typically localized and occurs in water that is less than 10 feet deep. Plant species diversity is usually at a maximum in mesotrophic lakes; numerous plant growth forms are present and result in a multi-layered plant canopy. Light penetration may limit plant growth but plants grow at depths greater than in eutrophic lakes and the total amount of plant growth in mesotrophic lakes is often as high as in eutrophic systems. Nutrients rarely limit plant growth in mesotrophic systems and growth of aquatic species is almost completely dependent on light penetration. Residents living next to reservoirs and lakes often report changes in plant coverage from year to year; these changes are typical of dynamic mesotrophic systems and are usually the result of changes in light penetration.

Depth zonation in eutrophic lakes is much less pronounced, with plant growth typically occurring at maximum depths of only 12 to 15 feet. Plant abundance is high, but plant diversity is much lower than in mesotrophic lakes and erect and canopy-forming plants predominate because light is often limited due to growth of phytoplankton. Native plants often produce populations that are large enough to be nuisances, particularly in high-use areas such as boat ramps and swimming areas. Light strongly limits plant growth and canopy-forming plants have a distinct advantage over plants that do not form canopies.

Hypereutrophic lakes typically have poorly developed aquatic plant communities and plants rarely grow in water more than 6 feet deep. Some emergent and floating plants can be found, but submersed plant growth is greatly reduced and typically only canopy-forming species are able to establish. Plants that are able to colonize hypereutrophic lakes often grow to nuisance levels. High algal production results in dense blooms that intercept available light. As a result, plant diversity is low and the abundance of rooted plants is typically lower than in eutrophic lakes.

So what should a typical lake look like? Well, that depends. Without human-mediated nutrient loading from sewage treatment plants and runoff from fields and residential areas, hypereutrophic lakes would be rare occurrences. Therefore, the natural state of a typical lake would include a littoral zone dominated by aquatic plants. Even in eutrophic lakes, nuisance populations of native plants would likely be localized and would cause problems only when the plants interfere with recreational or other uses. However, the introduction of invasive exotic plants changes this dynamic, even in oligotrophic lakes.

Invasive plants

Invasive aquatic plants are generally defined as nonnative (from another geographic region, usually another continent) plant species that cause ecological and/or economic harm to a natural or managed ecosystem. Invasive aquatic plants often cause both economic and ecological harm.

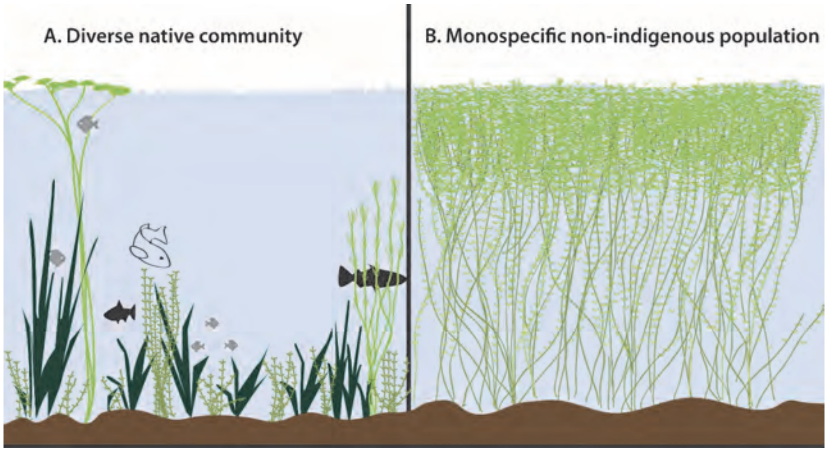
As invasive plants expand in a new area, they suppress the growth of native plants and cause localized extinction of native species. For instance, when Eurasian watermilfoil invaded Lake George in New York, growth of this exotic species reduced the total number of species in a permanent research plot from 21 to 9 over a three-year period. Invasive plant species can invade a particular zone of the depth profile and suppress the native plant species that normally inhabit that area. Colonization by invasive species may be less damaging in oligotrophic lakes because native plants can grow at much greater depths than invasive species. Native plants often persist in areas of mesotrophic lakes that are shallower and deeper than those colonized by invasive plants. Invasive plants dominate to the borders of eutrophic and hypereutrophic lakes, with native plants often confined to a shallow fringe around the lake.

Economic impacts	Ecological effects
Impair commercial navigation	Degrade water quality
Disrupt hydropower generation	Reduce species diversity
Increase flood frequency, duration and intensity	Suppress desirable native plants
Impair drinking water (taste and odor)	Increase extinction rate of rare, threatened and endangered species
Habitat for insect-borne disease vectors	Alter animal community interactions
Recreational navigation impairment	Increase detritus buildup
Interfere with safe swimming	Change sediment chemistry
Interfere with fishing	
Reduce property value	
Endanger human health, increase drowning risk	

Summary

Invasive plants reduce native plant growth and impede human uses of waters by forming dense surface canopies that shade out lower-growing native plants and interfere with water flow, boat traffic and fishing. Dense surface canopies also radically change the habitat quality for fish. Dense plant beds provide a place for small forage fish to hide and reduce the ability of predatory fish such as bass and northern pike to see their prey. This tends to lead to a large number of small, stunted forage fishes and poor production of game fishes.

Invasive plants also reduce water quality. While the increased biomass and dense canopies formed by invasive species tend to increase water clarity, they also lead to increased organic sedimentation. The fate of all lakes over geological time is to progress from lakes to wetlands to marshes to upland areas as lakes fill with sediments due to erosion and accumulation of organic matter. Exotic plants are also significantly more productive than native species and increase the rate of nutrient loading in the system by utilizing nitrogen and phosphorus from the sediment. For example, curlyleaf pondweed has been implicated in increased internal nutrient loading in Midwestern lakes because the plants absorb nutrients from the sediments and grow throughout the spring and summer, then die and release the nutrients into the water. Water also becomes stagnant under dense plant canopies that suppress or prevent oxygen recirculation. In addition, the amount of dissolved oxygen under dense plant canopies may be insufficient to support desirable fish species and may result in fish kills.



Many animal species are linked to specific native plant communities and the diversity of native communities provides a variety of habitats for aquatic insects and other fauna. Invasive plants reduce the diversity of native plant communities, which leads to a reduction in the diversity of both fish and aquatic insects. Therefore, invasive plants are harmful to the diversity and function of aquatic ecosystems and can have significant adverse impacts on water resources.

Photo and illustration credits:

Page 1: Littoral zone; Minnesota Department of Natural Resources
Page 2 upper: Aquatic plants illustration; John Madsen, USDA ARS
Page 2 lower: Secchi disk; Margaret Glenn, University of Florida
Page 3: Food pyramids; John Madsen, USDA ARS
Page 6: Heterogeneous and homogeneous plant communities; Robert Doyle, Baylor University