# Aquatic Plant Ecology Meets the Science of Plant Management

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The public has become aware of the issue of aquatic invasive species in recent decades due to the impact of species such as zebra mussels and silver carp. Aquatic plant managers, however, have been battling invasive aquatic plants for more than a century. The vast majority of nuisance aquatic plant problems are the result of an invasion by a non-native species. Invasive aquatic plants may not be reaching the headlines, but they have been affecting the bottom line for lake managers.

My goals in this article are to (1) identify what rooted aquatic plants need to grow, (2) identify the environmental drivers of plant community formation, (3) discuss the developments in selective control of invasive plants, and (4) suggest the implications to integrated management of aquatic plants.

## What Plants Need

To understand plant growth in lakes, the growth requirements of plants need to be understood. In general, plants need light, nutrients, water, carbon dioxide, oxygen, an appropriate temperature range for growth and survival, and a safe place to root (Table 1, Figure 1, Figure 2).

**Table 1.** Requirements for aquatic vascular plant growth, differentiated for terrestrial plants, emergent and submersed aquatic plants

| ***Requirement*** | ***Terrestrial Plant*** | ***Emergent Aquatic Plant*** | ***Submersed Aquatic Plant*** |
|---|---|---|---|
| Light | Not a problem | Not a problem | Water clarity attenuates the amount of light penetrating to depth |
| Nutrients | Soil the major source, mostly limited by N | Soil the major source, mostly limited by N | Soil the major source, mostly limited by N |
| Water | Water availability often limits growth | Availability not a problem | Availability not a problem |
| Carbon dioxide | $CO_2$ freely available from atmosphere | $CO_2$ freely available from atmosphere | Low concentration and rate of diffusion limits the rate of growth |
| Oxygen | Not a problem | $O_2$ availability to roots overcome by adaptations | $O_2$ availability to roots overcome by adaptations |
| Temperature | Temperature range limits growth | Temperature range limits growth | Temperature range limits growth |
| A safe place to establish | Disturbance limits establishment | Disturbance limits establishment | Disturbance limits establishment |

*Light*. Light attenuation by the environment is usually not a problem for terrestrial plants or emergent and floating aquatic plants, but light attenuation through the water column is the single most important environmental factor for the growth of submersed aquatic plants. The higher water clarity of a lake, the deeper submersed aquatic plants will grow. The relative ability of species to adapt to the light environment is the primary driver of submersed aquatic plant communities.

*Nutrients*. Like terrestrial plants, most aquatic plants (other than free-floating plants) derive their nutrients from the sediment or soil. Also like terrestrial plants, nitrogen rather than phosphorus is the limiting nutrient for aquatic plants. While external phosphorus loading reductions have had a significant impact on reducing the growth of algae, they have no effect in reducing the growth of rooted plants – and, in fact, the resulting improvements in water clarity have often resulted in increased depth range for rooted submersed plants.

*Water*. While the need for water is critical to the growth of terrestrial plants, aquatic plants typically do not lack for water (or the site would not be aquatic). The combination of abundant water with adequate nutrients in the sediment accounts for emergent plant communities being among the most productive ecosystems in the temperate zone.

*Gases*. Plants require both oxygen and carbon dioxide to sustain life. In the terrestrial environment, plants rarely have difficulty acquiring carbon dioxide. With

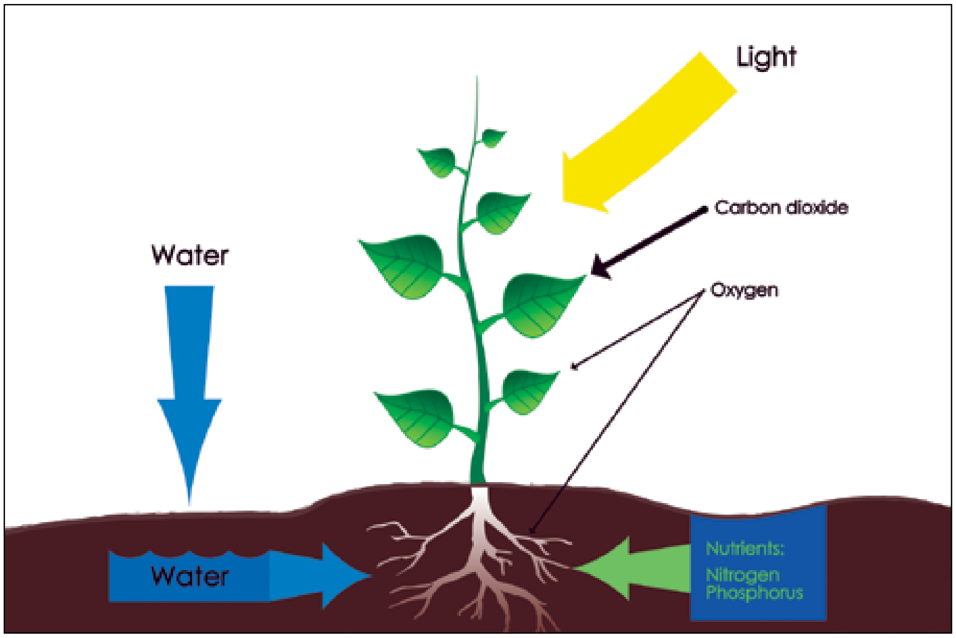

*Figure 1. A diagram of the requirements for the growth of a terrestrial plant.*

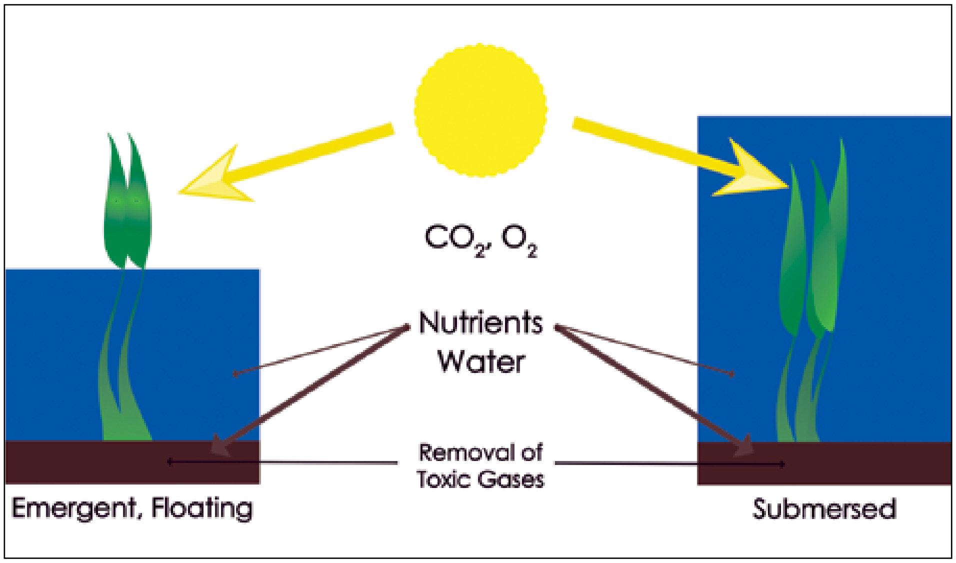

*Figure 2. A diagram of the requirements for the growth of an emergent or floating leaved plant (left) and a submersed plant (right).*

their leaves in the atmosphere, emergent plants likewise have little difficulty in acquiring carbon dioxide. Submersed plants, on the other hand, are in an environment in which carbon dioxide is in low supply, and the rate of resupply when used is slow. Submersed plants have developed a number of adaptations to acquire and store inorganic carbon for photosynthesis, with some species using bicarbonate in the water. Others actually store the carbon dioxide from cellular respiration and reuse it in photosynthesis – the ultimate in recycling.

Plant cells, like animal cells, need oxygen for cellular respiration. In terrestrial plants, the roots rarely have a problem in acquiring oxygen unless the soils are water saturated. Both emergent and submersed plants have adaptations for oxygenating the roots, including anatomical adaptations for transporting oxygen from photosynthesis to the roots.

*Temperature*. All plants require an appropriate annual temperature range for growth. Aquatic plants, however, have a two-fold advantage over terrestrial plants. Water tends to moderate temperatures in the summer, reducing heat stress. Water also offers a refuge from hard frosts. Plant vegetative propagules, like rhizomes and tubers, are not only buffered by soil, but by a layer of water that rarely freezes. This in part explains why otherwise tropical and subtropical plants have been surviving in waters north of their expected range, such as sightings of waterlettuce in the backwaters of the Mississippi River in southern Minnesota.

*A Safe Place to Establish.* Life as a plant can be tough. Plants have to be fortunate in finding a good place to establish with adequate water, nutrients, and light. This is particularly difficult for aquatic plants. Aquatic plants cannot establish in areas of heavy wave action, high current velocity, irregular water levels, and other disturbances. This accounts for some areas in lakes that do not support plant growth, even though there is adequate light.

## Environmental Drivers to Community Development

Aquatic plant communities are formed by the environmental factors such as water level fluctuation, water clarity, depth, and light availability.

*Zonation*. Aquatic plant communities tend to be organized in tiers by depth, which is referred to as depth zonation. If the lake has emergent, floating, and submersed species, the emergent plants will dominate in the shallowest depth zone, followed by floating plants, and finally submersed plants (Figure 3). The structure of plant growth is important for the habitat it creates for fish and other organisms; a native submersed plant community is more complex than is apparent from the surface, often with multiple canopy layers (Figure 4). While the dominant species are often the most visible, frequently the same species can be found across a broad depth range (Figure 5). The introduction of an invasive plant may disrupt the zonation pattern by suppressing or eliminating native species. An open and multilayered polyculture of native species is replaced by a dense monoculture of a single invasive species.

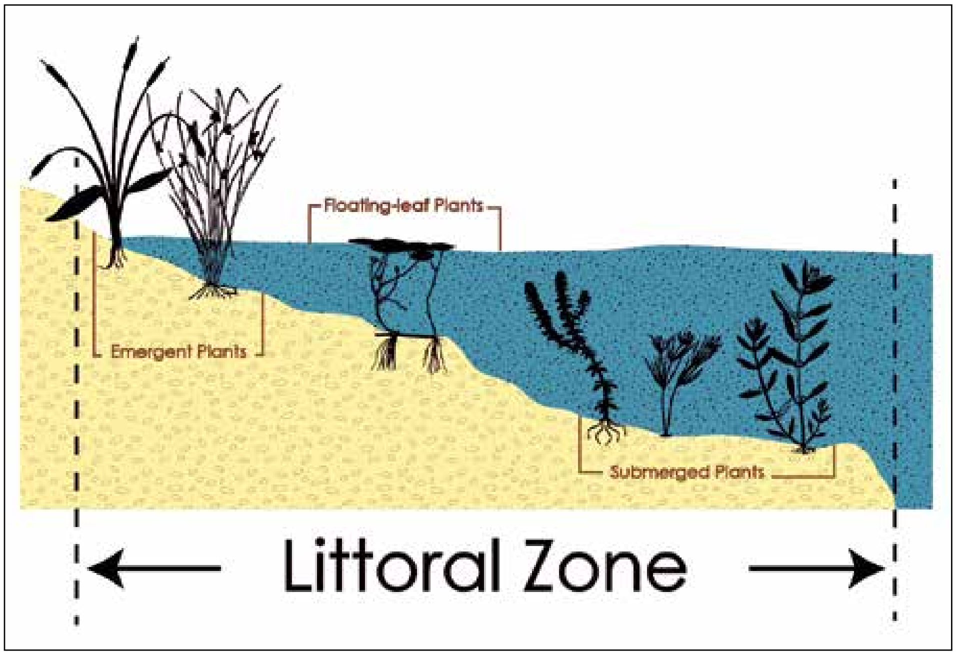

*Figure 3. Zonation of emergent, floating, and submersed plants by depth is a dominant structural feature in lake littoral zones.*

*Figure 4. The structure and composition of species of submersed plants are more complex than apparent from the surface, as demonstrated in this underwater photo from Pend Oreille Lake, ID.*

*Invasion*. The invasion process follows a highly predictable process: introduction, lag-phase, expansion, and domination (Figure 6). This process follows the most universal dynamic in biology; namely, the density-dependent population growth curve (or sigmoid curve). The sigmoid curve explains the population dynamics of bacteria on a petri dish, rabbits on a ranch, buffalo in a national park, and invasive plants in a new habitat. The sigmoid growth curve not only effectively models the population growth across time, but also the spatial expansion of that population, from a small area to an increasing area of the suitable habitat. The most important message of this is not to tolerate new invaders; manage the nonnative plant with early detection (look for new species) and rapid response. Rapid response may require having an agreement with regulatory agencies before a new invader is found, because once the plant is found the manager may not have much time before the plant moves into the exponential growth phase. Even natural resource biologists fall for the trap of waiting to see if a new invader will be a problem in their lake during the introduction and lag phase. Once the population starts to increase, it becomes exponentially more difficult to manage the population effectively. Some states have programs in which lake associations receive training to monitor for new species.

## Developments in Invasive Plant Management

Most people have heard of genetically modified crop organisms (GMOs) that allow the development of seed lines for plants that will tolerate high concentrations of a specific herbicide. Despite the varying opinions on this , it is the ultimate technological step in row crop weed management. Farmers can (usually) control all of the other plants in the field other than the desired crop. The goal, however, in managing invasive plant species is the exact opposite: control the target invasive plant without damage to the associated native plant species. Rather than develop a field with only one plant species, the goal is to remove one plant species (the invasive weed) and restore or maintain the native plants. Through a thorough understanding of the target plant's life history and biology, and an accompanying knowledge of native plant species, this lofty goal is often achievable in both terrestrial and aquatic habitats.

Curlyleaf pondweed provides a prime example of examining the life history and biology of a target plant to improve the management of it while reducing the impact on native plants (Woolf and Madsen 2003; Figure 7). Research indicated that the weakest point in the life history of curlyleaf pondweed was the turion; if turion production could be halted, then the population of curlyleaf pondweed could be reduced over time. Research also indicated that curlyleaf pondweed could be treated with herbicides much earlier in the season than previously thought possible (April as opposed to June), before native plants started growing in May (Netherland et al. 2000). An understanding of life history principles can be applied to any species

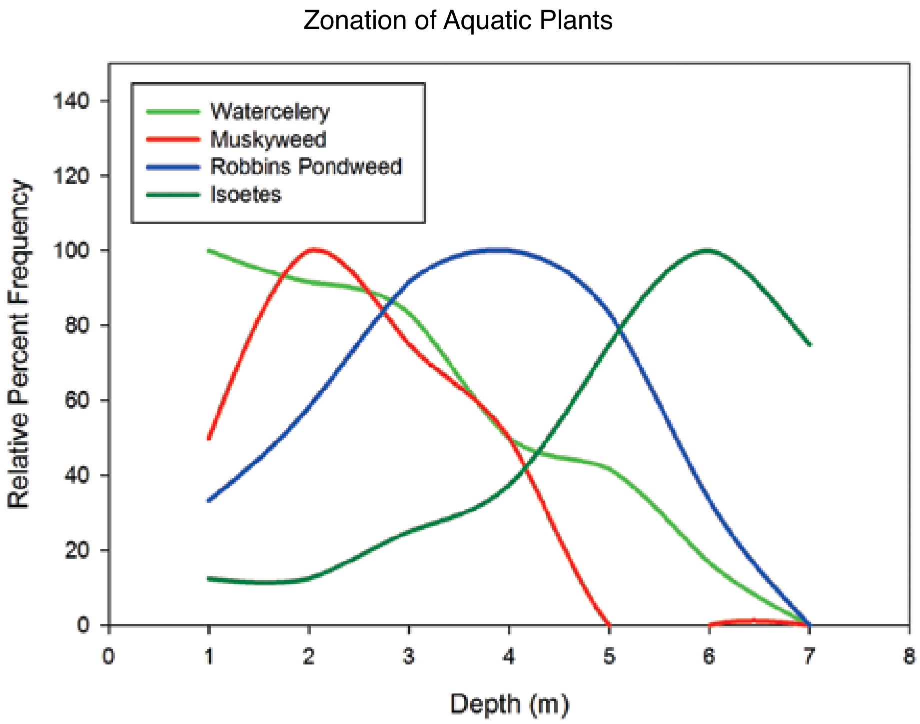

*Figure 5. Graph of relative plant frequency from Lake George, New York, demonstrates that, while species vary in their dominance across depth, they are often present across a broad depth range.*

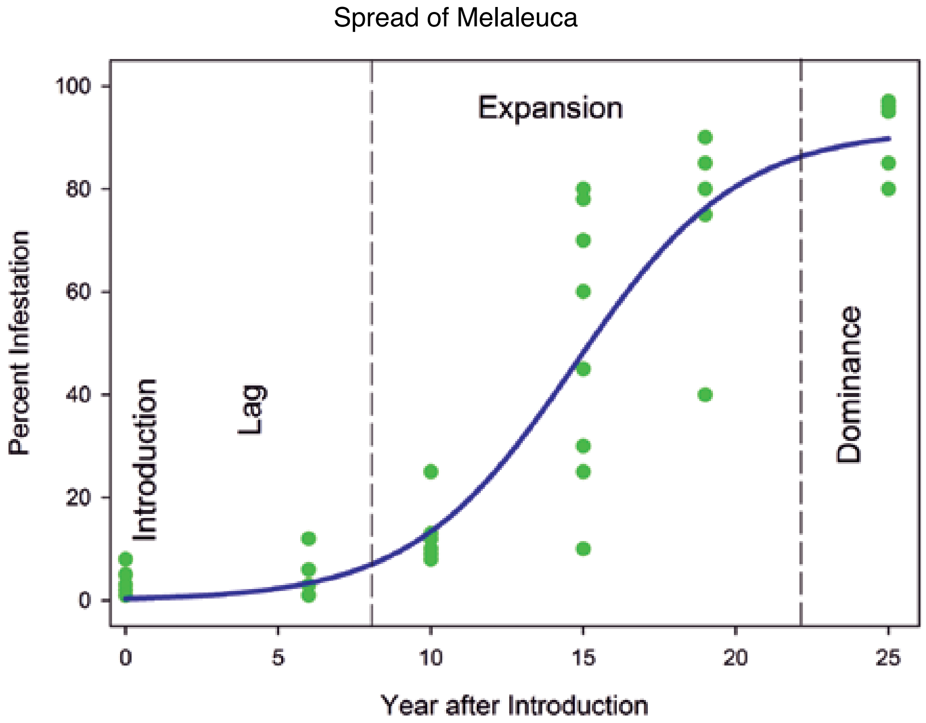

*Figure 6. The spread of melaleuca in the South Florida Water Management District as percent infestation from time of introduction to complete coverage. Data taken from Laroche and Ferriter 1992, figure redrawn.*

and any management technique, including biological, mechanical, chemical, or physical techniques.

*Biological control*. The most predictable and effective form of biological control for selective control of invasive weeds is the classical approach: going overseas to find insects that feed on the target plant. Once a potential insect is found, the insect then goes through a series of studies to ensure that it is host specific and will not pose a threat to agriculture or natural resources. This is an expensive process, usually funded at the federal government level, and may require decades to bring a new agent to the point of release. Often, more than one insect for a target plant is needed to be effective. While several agents have been successful in controlling a given target plant, most have not been effective in managing weed populations. Because of the cost of discovery and development, biological control programs on aquatic plant species have decreased in the past decade.

*Chemical control*. Selective management with herbicides typically follows a narrow path between ineffective control of the target plant, and increased damage to native plant species.

Herbicide selectivity is based on the timing and areal extent of application, the phenology and life history of the target plant, and the response of the weed to the concentration and exposure time of the herbicide in the water. With the discovery of hydrilla populations that have developed resistance to fluridone, a number of new chemicals have been or are in the process of being labeled for aquatic use. All of these active ingredients are already used in terrestrial applications in either agriculture or vegetation management. In addition, both old and new active ingredients have been reexamined to develop new use patterns that can effectively manage target plants while reducing impact on native plant populations. For example, a new herbicide to aquatics, flumioxazin, has been found to be effective on waterlettuce when injected into the water, but does not damage most native floating or emergent plant species.

*Mechanical and physical control*. While no new technologies have been developed in the last decade for managing invasive weeds, these techniques are being timed to specific stages in the target plant's life history to improve their effectiveness and diminish impacts on native plant communities.

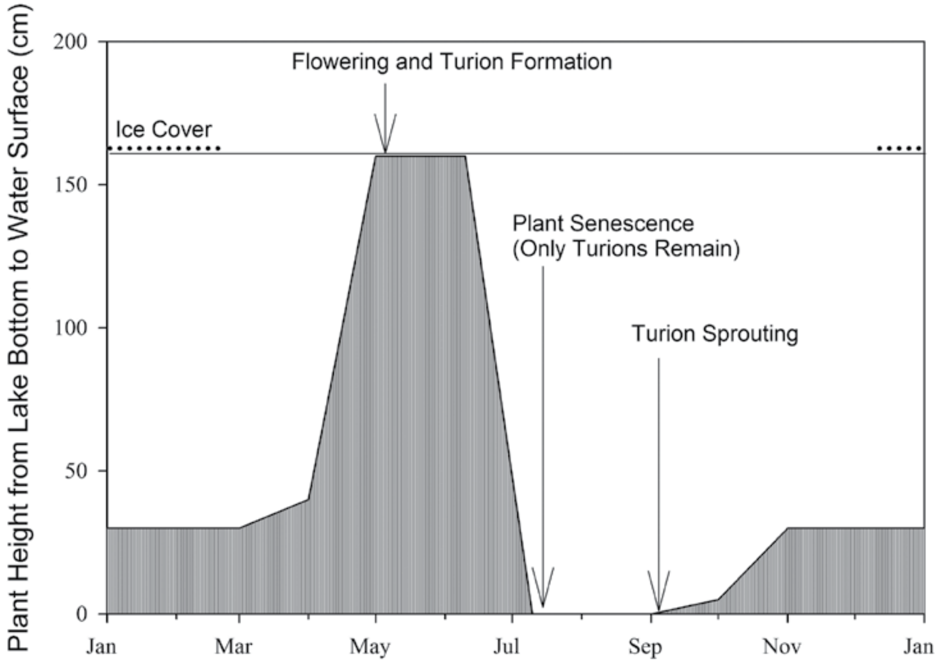

*Figure 7. The life history of curlyleaf pondweed in a Minnesota lake. Curlyleaf pondweed oversummers as a turion; preventing turion formation in early spring has been found to be effective in reducing the population over time.*

### Integrated Plant Management

Integrated Plant Management (IPM) is a process of decision-making on plant management involving the use of multiple control techniques based on regular monitoring and assessment of plants and the environment, to manage the plants while minimizing environmental and ecological impacts, and incorporating knowledge of the biology and ecology of the target plant. For example, in a lake with Eurasian watermilfoil filling the littoral zone, IPM involved a single whole-lake herbicide treatment in the first year. The following years, benthic barriers and rigorous monitoring with judicious hand removal were used to further reduce target plant populations. Twenty years on this plan have kept Eurasian watermilfoil eradicated from Long Lake, Washington. Integrated Plant Management recognizes that all management techniques have good and bad effects, and that failing to manage the plant may also result in ecological degradation. IPM requires regular monitoring and assessment of management activity, and decisions on the next step based on an adaptive approach to controlling the plant population.

### References

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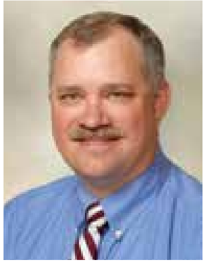

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