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Control points in the phenological cycle of Eurasian watermilfoil

by
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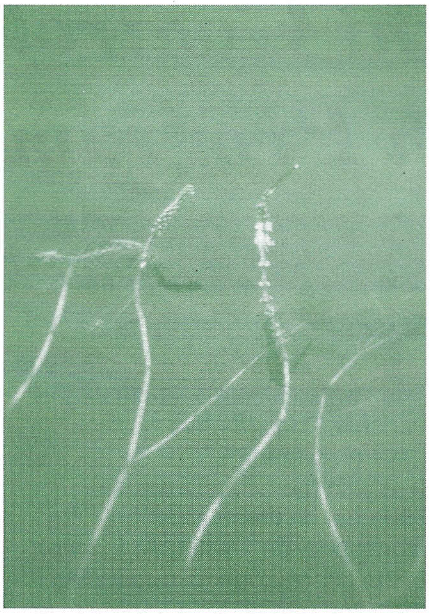
Underwater photo of a dense canopy of Eurasian watermilfoil

The growth form of submersed aquatic plants can be highly variable. Many native species have growth forms that do not interfere with the use of water resources. In these situations, the plants provide a valuable function in the littoral zone, by producing food and habitat for a variety of organisms. However, some species produce dense surface canopies that may create a nuisance. One of these, Eurasian watermilfoil (*Myriophyllum spicatum* L.), can impact extensive areas because of its dense canopy growth form, its highly aggressive and weedy characteristics, and a long growing season.

Eurasian watermilfoil is native to Europe, Asia, and northern Africa and was first observed in North America in 1942 near Washington, DC (Couch and Nelson 1985). It has become a widespread problem throughout the United States (Couch and Nelson 1985) and Canada (Aiken, Newroth, and Wile 1979).

Eurasian watermilfoil spreads both within and between lakes by the formation of vegetative autofragments, which are stem pieces that break off the plant through stem abscission (Aiken, Newroth and Wile 1979, Madsen, Eichler, and Boylen 1988). Dense colonies may also spread locally by the growth of root crowns (Madsen,



The inflorescence of Eurasian watermilfoil consists of staminate and pistillate flowers that are wind-pollinated above the surface of the water

Eichler, and Boylen 1988). Although large numbers of seeds are produced, they do not appear to be significant to overwintering or spread (Madsen and Boylen 1989). Dense beds can spread rapidly, shading out native plants and reducing overall plant community diversity (Madsen and others 1991).

The Aquatic Plant Control Research Program supports studies in four technology areas (Biological Control, Chemical Control, Ecological, and Simulation technologies) to better manage populations of Eurasian watermilfoil. The Biological Control technology area is investigating fungal pathogens and insects as potential biocontrol agents for managing Eurasian watermilfoil populations. The Chemical Control technology area examines concentration/exposure time relationships for aquatic herbicides and evaluates the applicability of these relationships on an operational level. The Ecological technology area examines the environmental parameters that determine the distribution and abundance of Eurasian watermilfoil. The Simulation technology area has been developing growth models for Eurasian watermilfoil, as well as predictive models for specific control techniques used on this species, such as herbicides, harvesting, and grass carp.

The study of phenological weak points in the life strategies of target aquatic plants will indicate the potential timing of management tactics from all technology areas. The objective of examining phenological cycles in nuisance aquatic plants is to more effectively manage these species by providing a mechanistic approach for optimizing management successes.

One mechanism to optimize the timing of management tactics is to examine the storage of carbohydrate reserves by plants, and apply control tactics when reserves are at their lowest in storage organs. Low points in the storage of carbohydrate reserves can then be correlated to observable phenological phenomena, such as the onset of flowering.

To illustrate, a hypothetical curve of total nonstructural carbohydrates (TNC) in a plant storage organ is shown as Figure 1. Stored carbohydrates are used by the plant from the onset of regrowth in late February until late June, when storage concentrations no longer decrease, but begin to increase. Carbohydrate production is in excess of the metabolic requirements of the plant, and excess production is stored. The late-June time indicated in Figure 1 is a primary control point. Additional observations also indicated that this control point coincided with the initiation of flowering. Therefore, the optimal time to apply a management tactic would be the onset of flowering.

This approach was successfully demonstrated in cattail (*Typha glauca*) by Linde, Janisch, and Smith (1976), in which a late-June control point was identified by low carbohydrate reserves in the rhizome, which coincided with the appearance of staminate (pollen-producing) inflorescences. A similar approach has been used to successfully control terrestrial weeds, such as quackgrass (Schirman and Buchholtz 1966). These approaches have only recently been investigated for aquatic

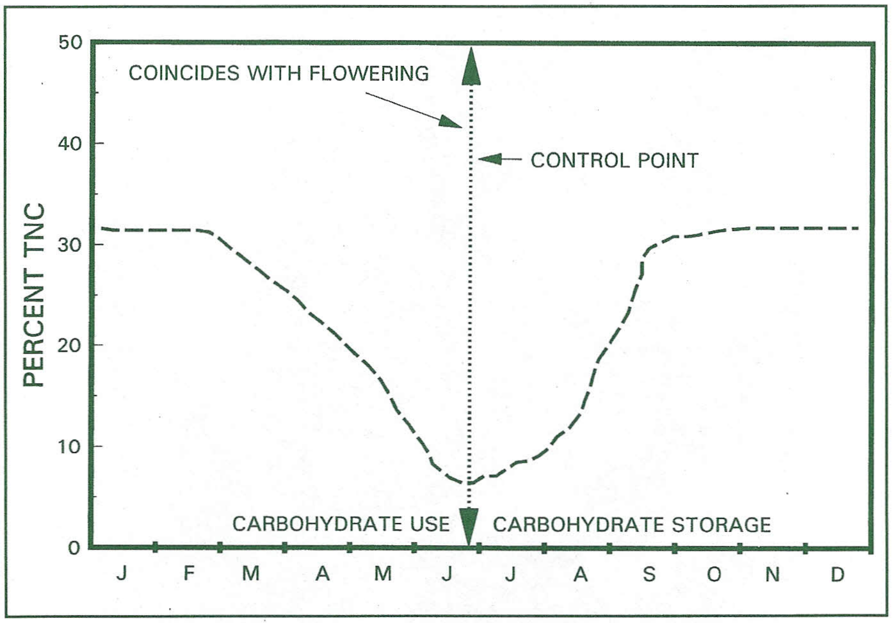


Figure 1. Hypothetical carbohydrate concentration (TNC, percent of dry weight) and control point identification

plants by researchers at the Waterways Experiment Station (WES).

Waterhyacinth (*Eichhornia crassipes*), hydrilla (*Hydrilla verticillata*), Eurasian watermilfoil, and alligatorweed (*Alternanthera philoxeroides*) are considered by the Corps of Engineers to be the major nuisance aquatic plants in the United States. The goal is to perform phenological control point studies on all four species.

Small-scale studies of waterhyacinth, conducted at WES, concluded that control points based on the phenology of the plant and carbohydrate storage patterns occurred in early spring and in mid-September to early October, before substantial storage had occurred in stembases (Luu and Getsinger 1988, 1990). These studies were verified by pond-scale studies at the Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, Texas, in which the same two control points were observed for waterhyacinth. In addition, the developmental stage of the population was noted as an important factor. That is, waterhyacinth populations should be controlled before large mature plants can develop (Madsen, Luu, and Getsinger 1993). This result substantiates the current practice of maintenance management.

Carbohydrate allocation in Eurasian watermilfoil

Many aquatic plants have well-defined storage organs for carbohydrate reserves, such as the tubers of sago pondweed (*Potamogeton pectinatus*) and hydrilla, the turions in curly-leaf pondweed (*P. crispus*) and American pondweed (*P. nodosus*), the rhizomes in cattail and yellow pond-lily (*Nuphar advena*), and the stembase of waterhyacinth (Madsen 1991). However, Eurasian watermilfoil lacks any distinct, specialized anatomical structure for storage. Instead, carbohydrates are stored in the lower nonphotosynthetic shoots and the root crown, which is a mass of stems at the sediment-water interface that initiates new shoot growth.

In Figure 2, the carbohydrate production and storage "compartments" are diagrammed. The upper photosynthetic shoots produce excess carbohydrates, which are translocated as sugars to the lower stems and root crown. In the storage compartment (lower shoots and root crown), sugars are converted to starch for long-term storage. When plant carbohydrate requirements exceed plant production capability, carbohydrates in the storage compartment are remobilized and exported to the tissues requiring additional carbohydrates ("usage" in Figure 2).

During a hypothetical growing season, new spring growth will consume stored carbohydrates (Figure 3). Carbohydrate storage is high, and is being exported to overlying shoots. At an undetermined point, plant production exceeds plant requirements, and carbohydrates are now transported to the storage compartment. Since stored carbohydrates are low, this time period is the point at which control should be optimal. Carbohydrate production and storage continues in autumn, with the carbohydrate content of the storage compartment increasing to higher levels. Carbohydrate stores remain high throughout the winter, with little used by the plant during

Students assisted in sorting and processing the plant samples

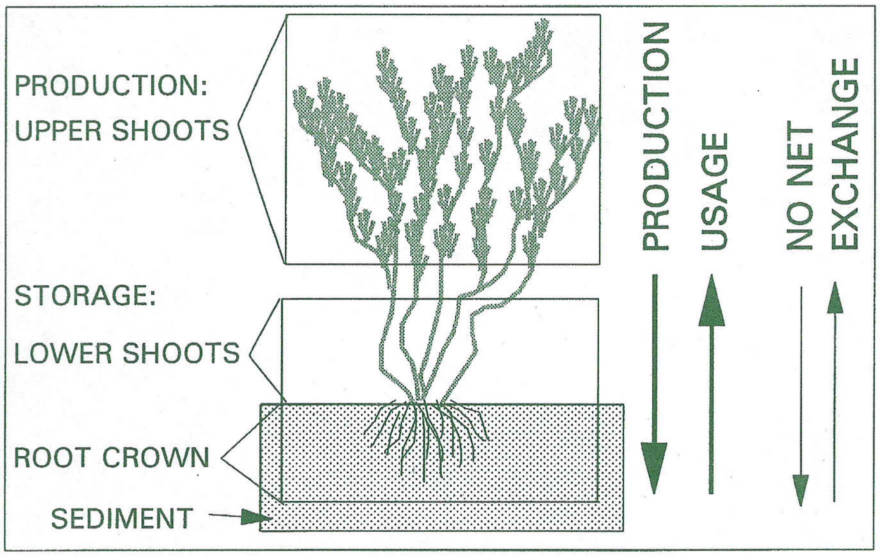


Figure 2. Carbohydrate production and storage areas in a Eurasian watermilfoil plant

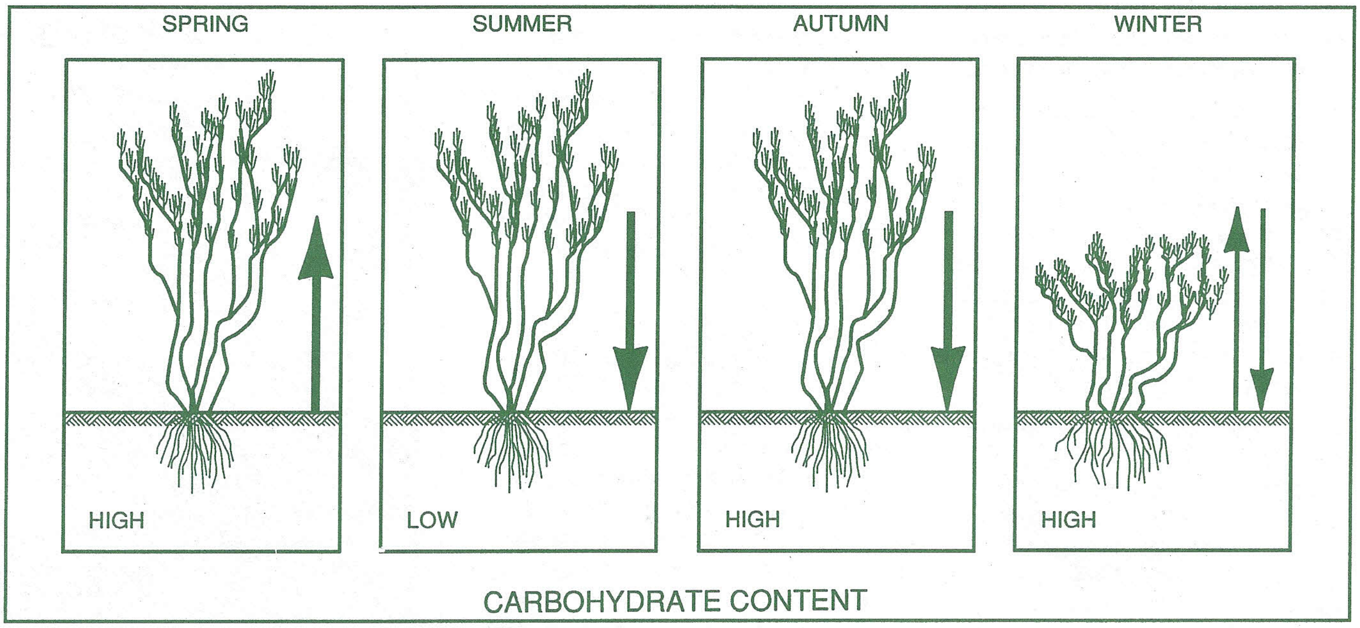


Figure 3. Seasonal cycle of carbohydrate usage and storage in Eurasian watermilfoil

a dormancy period, indicated by no net exchange in the diagram.

Several studies substantiate the potential for a control point in Eurasian watermilfoil. Data from Perkins and Sytsma (1987) for a population in Lake Washington, in west-central Washington state, showed a late-May control point, with stored TNC falling to 7 percent. Studies of carbohydrate storage in Eurasian watermilfoil in Lake Wingra, Wisconsin, indicated potential control points in late June or early July of one year, and in mid-May in a subsequent year (Titus and Adams 1979). Because these studies were not performed to determine phenological control points, neither of them examined potential phenological indicators to correlate to the carbohydrate minima.

Surface and underwater light intensity was examined in phenological studies of aquatic plants conducted at LAERF

Experimental approach for Eurasian watermilfoil

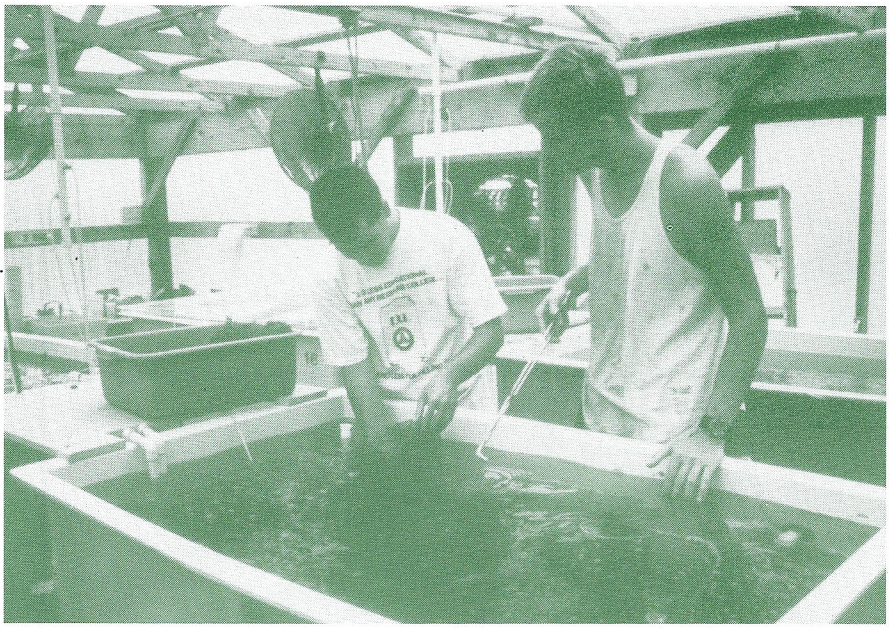
Research being conducted at the LAERF to investigate the phenology of Eurasian watermilfoil is focused on five areas of study, described below.

Seasonal growth and allocation studies

Seasonal growth and allocation of biomass and carbohydrates is being examined through whole-pond studies. Samples taken throughout the growing season are separated into lower and upper shoots, root crowns, inflorescences, and autofragments. These studies will provide the best indication of a control point based on carbohydrate storage.

Growth and colonization trends

Growth rate and seasonal colonization trends are being examined in an extensive pond study in which



Greenhouse controlled-temperature tanks were used to study the phenology of aquatic plants

Eurasian watermilfoil was planted in 6-liter sediment-filled pots in spring, summer, fall, and winter, to determine when colonization and growth would be most successful. Establishment and colonization are important phases of the Eurasian watermilfoil invasion process that have not been studied.

These studies, carried through two growing seasons, will indicate if there is a lag time in the development of dense beds that can be exploited for management of new colonies.

Temperature-dependent allocation patterns

Temperature-dependence of biomass and carbohydrate allocation will be examined in greenhouse tanks with controlled temperatures. These studies will indicate if patterns observed seasonally are in direct response to water temperatures, as well as indicating the difference in growth and production based on water temperature alone.

Seasonal spread dynamics

Seasonal control of the spread of Eurasian watermilfoil is being examined in a series of pond experiments using a grid system that allows the mapping of all rooted plants and fragments. The grid systems are examined regularly, which allows the computation of seasonal expansion and decline by both runners and fragments (Madsen, Eichler, and Boylen 1988).

Seed production and germination

The importance of seeds to the overwintering and spread of Eurasian watermilfoil is still largely unknown (Madsen and Boylen 1989). Seed production and flowering is being monitored in Eurasian watermilfoil ponds. In addition, the effect of seed drying on subsequent seed germination is being investigated.

Preliminary results

Carbohydrate storage and control point identification

Eurasian watermilfoil carbohydrate concentrations reached their maximum at 20 percent in both roots and lower stems (Figure 4). Two control points occurred in this growing season, which is consistent with the bimodal biomass pattern observed. The first control point (mid-July) occurred simultaneously with the onset of autofragment production and after completion of the first seed production episode (Figure 5). The second control point (October) occurred at the peak of autofragment formation, and

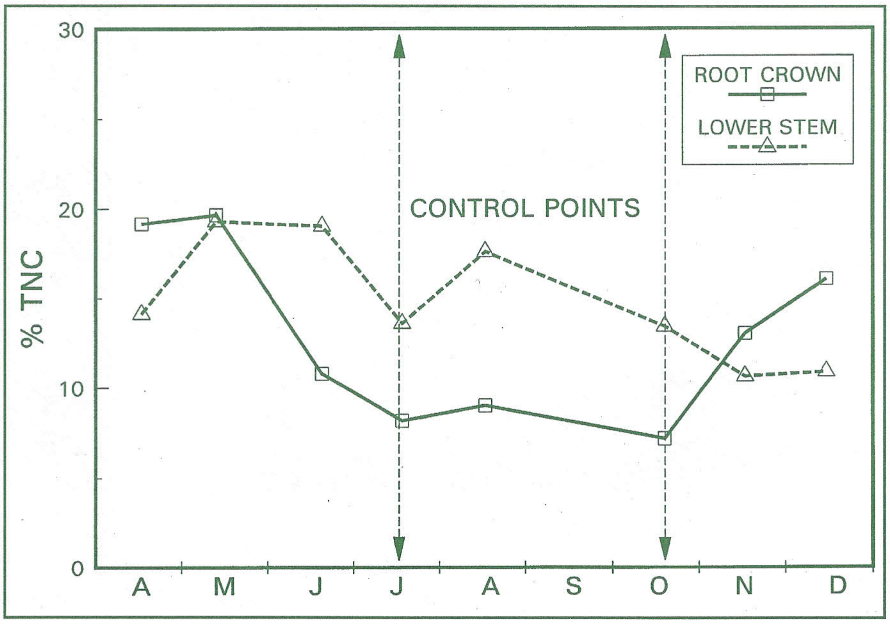


Figure 4. Total nonstructural carbohydrate concentration as percent of dry weight of root crowns and lower stems of Eurasian watermilfoil sampled at LAERF. Potential control points are indicated by the dotted arrows

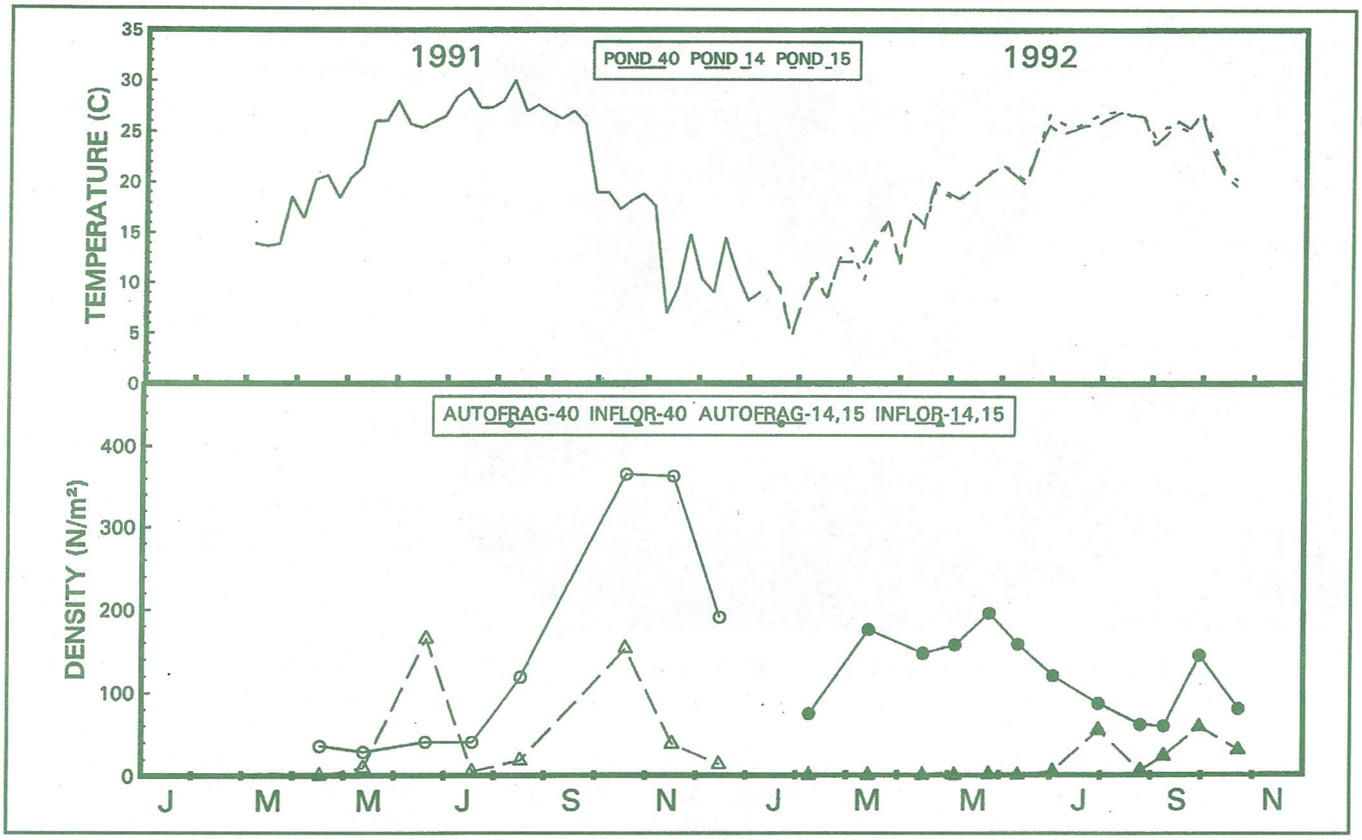


Figure 5. Pond water temperature (°C) (upper panel) and autofragment and inflorescence density (number per square meter) (lower panel) for Eurasian watermilfoil populations at LAERF for January 1991-October 1992

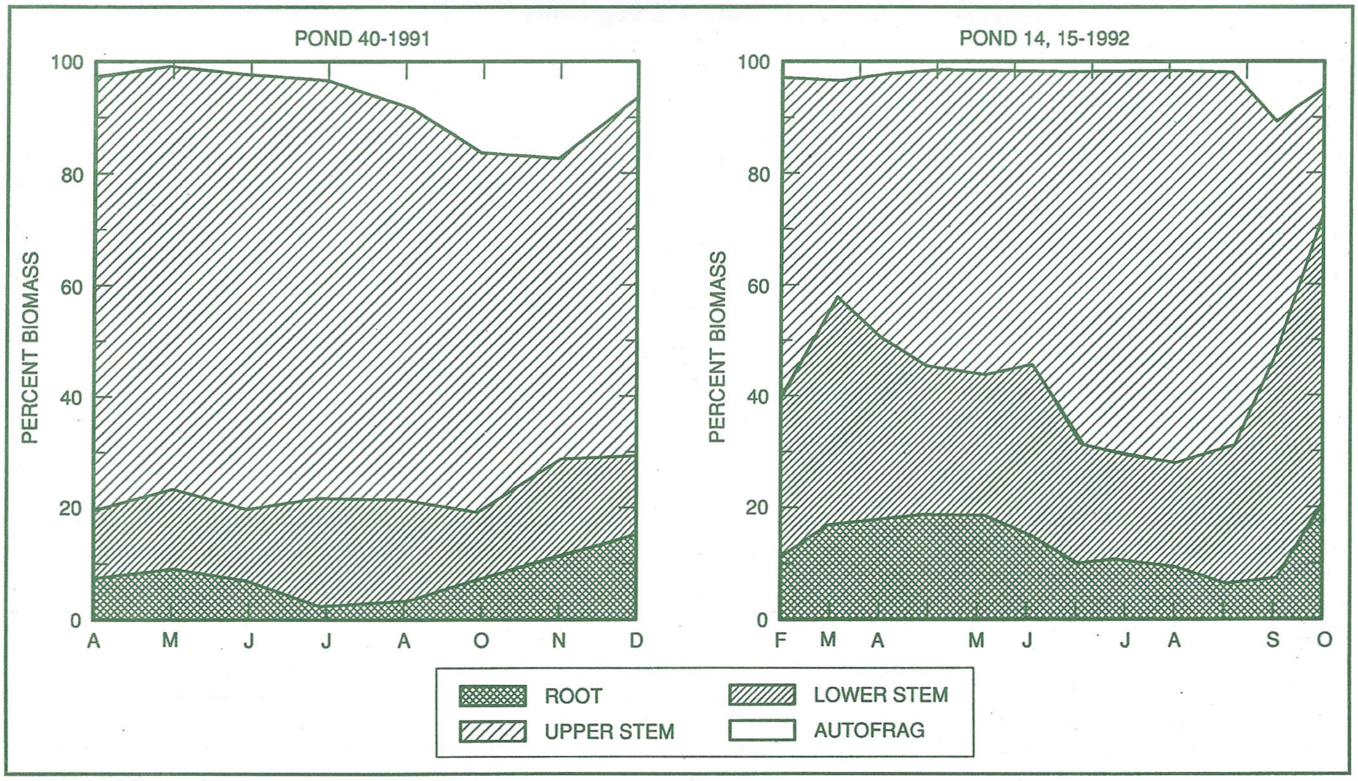


Figure 6. Biomass allocation as percent of total dry mass for Eurasian watermilfoil populations at LAERF (inflorescence was insignificant)

simultaneously with the peak of inflorescence production and onset of seed formation during the second biomass peak. Both control points can be exploited for management purposes—the first, to prevent excessive summer growth, and the second, to prevent successful overwintering. Different populations may exhibit different patterns, and populations may also vary between years.

Biomass allocation patterns

Eurasian watermilfoil biomass was predominantly allocated to the upper stems, a strategy that is consistent with maximizing photosynthetic and production capabilities (Figure 6). Lower stem and root crown allocation is consistent across season. In both 1991 and 1992, a strong peak in allocation to autofragment production in late summer and fall was noted. This was the chief form of vegetative propagation, and used up to 20 percent of total plant biomass. Autofragment formation may be linked to the peak of flowering and seed set, which is also related to the length of growing season and water temperature (Figure 5). Autofragments can survive independently in the water column, and stored carbohydrates may allow them to establish new colonies (Kimbel 1982, Madsen, Eichler, and Boylen 1988).

Conclusions

Studies of phenological control points based on the depletion of carbohydrate reserves have demonstrated that excellent potential exists for improving the management of Eurasian watermilfoil through the timing of control tactic applications. Studies of several northern tier populations by other investigators have indicated that a single control point occurs from mid-May through mid-July, but these studies did not correlate carbohydrate levels to other phenological events. Preliminary studies conducted at the LAERF indicate two potential control points, following the two peaks in population biomass. The first of these coincides with the end of the first inflorescence event, and the onset of senescence and initiation of autofragmentation. The second coincides with the second series of seed set and the peak in autofragment production. Continued studies on carbohydrate production and phenological events will refine this relationship. Studies of northern tier populations will assist in developing these relationships across the continent.

Future studies

Future studies will further define the relative importance of season, water temperature, and population age and development to the observed patterns of biomass and

A data-recording probe was used to obtain information on standard water quality parameters

carbohydrate allocation in Eurasian watermilfoil populations. These studies will help to explain the successes and failures of past Eurasian watermilfoil control efforts. More importantly, this research will enable managers to better predict control results in the future.

Demonstration projects will be designed to apply the concept of phenological control points to the management of Eurasian watermilfoil. These demonstration projects will focus on chemical technology areas, but similar control point applications could be used with other management technologies.

References

Aiken, S. G., Newroth, P. R., and Wile, I. 1979. "The Biology of Canadian Weeds; 34. *Myriophyllum spicatum* L.," *Canadian Journal of Plant Sciences,* Vol 59, pp 201-215.

Couch, R., and Nelson, E. 1985. "*Myriophyllum spicatum* in North America," *Proceedings of the First International Symposium on Watermilfoil* (Myriophyllum spicatum) *and Related Haloragaceae Species,* 23-24 July 1985, Vancouver, British Columbia, Aquatic Plant Management Society, Vicksburg, MS.

Kimbel, J. C. 1982. "Factors Influencing Potential Intralake Colonization by *Myriophyllum spicatum,*" *Aquatic Botany,* Vol 14, pp 295-307.

Linde, A. F., Janisch, T., and Smith, D. 1976. "Cattail—The Significance of Its Growth, Phenology and Carbohydrate Storage to Its Control and Management," Technical Bulletin 94, Wisconsin Department of Natural Resources, Madison, WI.

Luu, K. T., and Getsinger, K. D. 1988. "Control Points in the Growth Cycle of Waterhyacinth," *Aquatic Plant Control Research Program,* Vol A-88-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Luu, K. T., and Getsinger, K. D. 1990. "Seasonal Biomass and Carbohydrate Distribution in Waterhyacinth: Small-scale Evaluation," Technical Report A-90-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Madsen, J. D. 1991. "Resource Allocation at the Individual Plant Level," *Aquatic Botany,* Vol 41, pp 67-86.

Madsen, J.D. and Boylen, C.W. 1989. "Eurasian Watermilfoil Seed Ecology from an Oligotrophic and Eutrophic Lake," *Journal of Aquatic Plant Management,* Vol 27, pp 119-121.

Madsen, J. D., Eichler, L. W., and Boylen, C. W. 1988. "Vegetative Spread of Eurasian Watermilfoil in Lake George, New York," *Journal of Aquatic Plant Management,* Vol 26, pp 47-50.

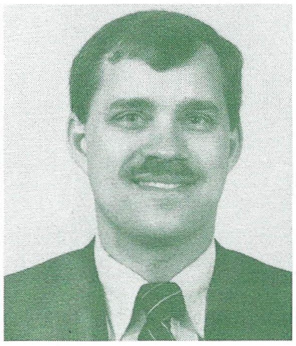
Madsen, J. D., Luu, K. T., and Getsinger, K. D. 1993. "Allocation of Biomass and Carbohydrates in Waterhyacinth (*Eichhornia crassipes*): Pond-scale Verification," Technical Report A-93-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Madsen, J. D., Sutherland, J. W., Bloomfield, J. A., Eichler, L. W., and Boylen, C. W. 1991. "The Decline of Native Vegetation Under Dense Eurasian Watermilfoil Canopies," *Journal of Aquatic Plant Management,* Vol 29, pp 94-99.

Perkins, M. A., and Sytsma, M. D. 1987. "Harvesting and Carbohydrate Accumulation in Eurasian Watermilfoil," *Journal of Aquatic Plant Management,* Vol 25, pp 57-62.

Schirman, R., and Buchholtz, K. P. 1966. "Influence of Atrazine on Control and Rhizome Carbohydrate Reserves of Quackgrass," *Weeds,* Vol 14, pp 233-236.

Titus, J. E., and Adams, M. S. 1979. "Comparative Carbohydrate Storage and Utilization Patterns in the Submersed Macrophytes *Myriophyllum spicatum* and *Vallisneria americana,*" *American Midland Naturalist,* Vol 102, pp 263-272.



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APCRP Briefs Visitors from USDA Agricultural Research Service

At the invitation of Lewis Decell, Program Manager of the Aquatic Plant Control Research Program (APCRP), representatives of the U.S. Department of Agriculture's ARS visited the Environmental Laboratory (EL) at Waterways Experiment Station on May 11-13. Dr. Mary Carter (Director, Southeast Region, USDA-ARS), James Hilton (Associate Director, USDA-ARS), Joe Antognini (National Program Leader, Weed Science, USDA), and Dr. James Krysan (National Program Leader, Pest Management Systems, USDA) toured the EL facilities that support aquatic plant research, as well as the Lewisville Aquatic Ecosystem Research Facility in Lewisville, Texas. The ARS visit allowed for very productive discussions of past and current cooperative research activities between the APCRP and ARS, and helped to define cooperative efforts for the future.

28th Annual Meeting, Aquatic Plant Control Research Program

The 28th Annual Meeting of the Aquatic Plant Control Research Program (APCRP) will be held November 15-18, 1993, at the Radisson Plaza Lord Baltimore Hotel in Baltimore, Maryland. Meeting information and a draft agenda will be mailed by mid-September 1993. In conjunction with the annual meeting, the FY 95 Civil Works R&D Program Review for the APCRP will be held on Thursday afternoon, November 18. For further information, contact Bob Gunkel, Assistant Manager, APCRP, at (601) 634-3722.

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In this issue, a study to identify the control points, or weak points, in the phenological cycle of Eurasian watermilfoil is reported. The control points are identified based on the relationship between growth characteristics and carbohydrate allocation. These findings will enable field personnel to select the optimal time for control efforts. Some preliminary results are presented.

AQUATIC PLANT CONTROL RESEARCH PROGRAM

This bulletin is published in accordance with AR 25-30 as one of the information dissemination functions of the Environmental Laboratory of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from the Corps of Engineers' nationwide Aquatic Plant Control Research Program (APCRP) can be rapidly and widely disseminated to Corps District and Division offices and other Federal and State agencies, universities, research institutes, corporations, and individuals. Contributions are solicited, but should be relevant to the management of aquatic plants, providing tools and techniques for the control of problem aquatic plant infestations in the Nation's waterways. These management methods must be effective, economical, and environmentally compatible. The contents of this bulletin are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such products. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Decell, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call AC 601/634-3494.

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