PLANT PATHOGENS AS BIOCONTROLS OF AQUATIC WEEDS[1]

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The papyrus reed when seen for the first time, or carved in stone upon some Egyptian monument, is a beautiful plant with delicate arching fronds making a hieratic pattern against the sky. But when it is multiplied to madness, hundreds of square miles of it spreading away like a green sea on every side, the effect is claustrophobic and sinister . . . (43).

Introduction

Ours differs from many previous articles in the *Annual Review of Phytopathology* for it heralds a topic new to our field rather than re-examines an old one. We concur with Wilson (86) who chose the term "commencement" to summarize his treatise on a similar topic. Plant pathologists are traditionally hired to confront and subdue microbes that would impair the productivity of our crop plants. However, we have largely overlooked those microbes that would be our allies in controlling noxious weed species. In our preoccupation with crop species, virtually all of which are terrestrial, we have also overlooked the many plants that exist in aqueous habitats. Our neglect is a matter of record. Not a single disease is listed in the *Index of Plant Diseases* (32) for our three most notorious waterweeds, water hyacinth (*Eichhornia crassipes*), Eurasian watermilfoil (*Myriophyllum spicatum*), and hydrilla (*Hydrilla verticillata*), currently pests of considerable economic significance. Thus, we have chosen to write a perspective rather than a review. It is our intention to: (*a*) explain the problems created by infestations of waterweeds, (*b*) enumerate the causes of these problems, and (*c*) consider the relationship and potential of plant pathology to the control of waterweeds.

The Problems Created by Waterweeds

As we use ever-increasing quantities of water, perhaps our most important natural resource, we find ourselves on a collision course with rapidly spreading infestations of waterweeds. Aquatic plants in reasonable numbers are not objectionable and are even valuable. Excessive populations, however, create havoc in our waterways. They clog the grids and sluices of hydroelec-

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tric and irrigation installations, and can render navigation all but impossible on badly infested bodies of water.

Recreational activity on weed-infested lakes is sorely curtailed. Weeds make swimming, boating, and fishing not only unpleasant but hazardous. Fishing is affected because gamefish are at a competitive disadvantage to "trash" species in waters heavily infested with weeds. In many instances, fish populations become exterminated altogether when dissolved oxygen levels are depleted through respiration and decomposition of senescing vegetation. Large accumulations of aquatic vegetation are aesthetically unpleasant, and decomposing masses along shorelines can create odoriferous nuisances. The end result, obviously, is a dramatic depression in values of waterfront properties. In Florida alone, this loss has been estimated to exceed 50 million dollars annually (33).

Excessive waterweed populations can also cause reservoirs and irrigation canals to lose water at disproportionate rates. Rather than conserving moisture by covering the water's surface, weeds such as water hyacinths can, through evapotranspiration, cause reservoirs to lose water at rates many times faster than on open water (31, 66). Timmons (80) reported a loss of 2.425 $\times 10^9$ cubic meters of water annually due to evapotranspiration of aquatic and ditchbank weeds in irrigation systems in 17 western states in the U.S. This loss was conservatively valued at $39,300,000.

Water weeds also compete with cultivated species in areas of the world where lowland rice and other types of subaquatic crops are grown. Paddies allowed to fallow may become so overrun with noxious aquatic vegetation that they must be abandoned (31, 66).

Perhaps most insidiously of all, waterweeds are havens for such dangerous vectors and alternate hosts of human pathogens as mosquitoes and snails. It is unsafe to live near waterbodies choked with weeds in areas of the world where malaria, encephalomyelitis, filariasis, and schistosomiasis occur (20, 31). Plants such as water lettuce (*Pistia stratioites*) further contribute to human misery by providing a clandestine source of air to the *Mansonia* mosquito, a vector of eastern encephalitis virus and rural filariasis. The larvae and pupae of all other mosquitoes must surface to obtain air and thus are subject to suffocation on water coated with oil films. The *Mansonia* mosquito is able to acquire oxygen without ever surfacing, by puncturing the roots of water lettuce. Controlling this mosquito is contingent upon weed control (83).

Aquatic plants occur throughout the world, and many weed species have become cosmopolitan. Although these plants are frequently able to extend their range latitudinally much more readily than terrestrial plants, due to the more constant edaphic conditions of the aquatic environment (66), the most frequent confrontations of man with waterweeds have been in the tropics and subtropics. Waterweeds grow most profusely in regions with long hours of sunshine and mild climates. Areas such as Central Florida and the Bayou region of Louisiana, with numerous shallow lakes and streams, are especially prone to waterweed problems. Waterweed infestations are especially serious in localities where the indigenous population is dependent upon its waterways for survival, but whose economy, technology, or political stability is such that they are unable to cope with the problem. For example, water hyacinth first appeared on the Congo River in 1952, and within 3 years had spread some 1000 miles from Leopoldville to Stanleyville. Their presence blocked the river and drastically reduced the fish populations, depriving the riverine inhabitants of their chief means of transportation as well as their primary source of protein. The Belgian government mustered ships and aircraft, and applied herbicides to these weeds to keep them under partial control. By 1957, the river could again be used. These control efforts unfortunately were interrupted during the tumultous years following the Congo's independence, and the hyacinth again reclaimed the river to bring additional suffering to the inhabitants (31, 36, 66).

The Causes of the Waterweed Problem

Man is chiefly to blame. He has acted as the chief disseminating agent of pestiferous aquatic plants. There is a tendency among water plants to reproduce vegetatively. In fact, many lack the capacity to produce seeds, and therefore may be without a means of aerial transportation over long distances (66). Without man's help, most noxious species would thus be restricted to the continents from which they originated, and sometimes even to finite bodies of water. Man has unwittingly introduced many weeds. Alligatorweed (*Alternanthera philoxeroides*) was unknown in the United States until about 1894 when it arrived from South America as a stowaway in ballast of ships (82, 84). Away from its natural enemies and finding its new habitat favorable, this pest soon became established throughout the southeast, particularly in Louisiana and South Carolina.

Many aquatic plants have been introduced to new habitats deliberately. In his quest for beauty, man has imported aquatic plants from around the world, cultivated them, and carelessly allowed them to escape. The most famous of all aquatic pests imported under the guise of an ornamental is the water hyacinth, introduced into the United States in 1884 when specimens of this plant were distributed to those attending the New Orleans Cotton Centennial Exposition. These plants originally came from Venezuela, and were much admired for their lavender blooms and exotic foliage. Soon they were to be found in garden pools and in farm ponds where they multiplied rapidly. Excess plants were simply discarded in nearby waterways. Water hyacinths were reported in Florida by 1890, and shortly after the turn of the century were found as far north as Virginia and as far west as California (52, 66). Interestingly, water hyacinths are said to have been transported to south Florida in the late 1890s by a cattleman who had the notion that the plant would make nutritious yet inexpensive cattlefood. Unfortunately the plants, though edible, proved low in nutrient value and could not be used for fodder. However, 50 years later they were costing the state 10 million dollars a year for eradication programs (85).

Water pollution is one of the chief reasons we are having major difficulties with aquatic vegetation. Bodies of water age, through natural processes, from oligotrophy to eutrophy. As sediments accumulate, lakes become filled and are eventually transformed into bogs (38). Man has accelerated this process considerably by overnutrifying waterways with human, industrial, and agricultural wastes (26). Florida's 30,000-acre Lake Apopka is an extreme example. Until 1940, this lake had clear water and was nationally famous for its game fishing. Then—encouraged by fertilizers leaching from bordering citrus and vegetable farms, wastes from municipalities, and citrus processing plants—populations of water hyacinth, followed by algae, abounded. By 1965, this once pristine lake had been reduced to a hypereutrophic, sediment-filled body of water almost devoid of gamefish (9, 10, 69).

Man has further compounded the waterweed problem by redesigning nature's waterways. By constructing dams, he thwarts the periodic expelling of excess weed populations seaward during times of heavy rainfall, and thereby he provides placid havens for the proliferation of aquatic vegetation. Man-made lakes throughout the world are infested with noxious water plants. For example, the Tennessee Valley Authority's lakes are severely infested with Eurasian watermilfoil (74), Ghana's Lake Volta is covered with water lettuce, and Nicaragua's Lake Apanas has a severe water hyacinth problem (31, 35, 66). Man-made canals for transportation, and ditches for irrigation and drainage interconnect isolated bodies of water and thus aid the spread of aggressive weed species. The continuity of England's inland waterways enabled Canada elodea (*Elodea canadensis*) to become firmly established throughout that country during the 1880s (66). The interconnected waterways of Florida enabled hydrilla to become established throughout the state within ten years after it was introduced near Miami.

The Status and Potential of Plant Pathology in Solving the Waterweed Problem

Attempts to control aquatic weeds include: (*a*) herbicidal applications, (*b*) removal and disposal with mechanical devices, and (*c*) biological control. Although the first two methods have considerable merit, they alone do not satisfactorily solve the overall aquatic weed problem because of expense and need for continuous treatments. Moreover, these two methods tend to be nonselective in their action. In the case of herbicide applications, the added pollution from their use detracts from the acceptability of this means of control.

Biological control methods may offer the greatest prospects for success by imposing a continual controlling force directly upon the pestiferous plants. Since many of our waterweeds are introduced species, it is logical to expect that searches in the native habitats of these plants would reveal numerous candidates that could be considered as biocontrols. Although several agents have already been evaluated as controls, none presently promises to solve the aquatic weed problem.

Certain snail species such as *Marisa cornuarietis* are promising, but could become pests themselves as they may also devour beneficial plants (6, 31, 67). Other snail species potentially useful as biological controls may be carriers of serious human and animal parasites (20). Herbivorous fish, particularly the white amur (*Ctenopharyngodon idella*), also offer some potential for the control of unwanted plants (6, 31). However, serious problems may result from the introduction of objectionable piscine forms such as the tilapia (*Tilapia melanotheron*). Moreover, there are relatively few herbivorous fish species from which to choose. The manatee (*Trichechus manatus*), although much publicized, offers little hope as it is difficult to breed and is close to extinction. One insect species, the alligatorweed flea beetle (*Agasicles hygrophila*) feeds only on alligatorweed and shows considerable promise for the control of this particular aquatic plant (40, 68). However, insects alone are not likely to control aquatic weed pests because there are relatively few phytophagous species capable of living beneath water. Most aquatic insects are either carnivorous or detrivourous; consequently, the number of insect species with potential to control submersed aquatic weeds is relatively limited.

Several authorities on waterweeds have specifically commented upon the lack of attention given to plant pathogens as biocontrols of aquatic weeds (6, 31, 66). The vast numbers of disease organisms [McNew (42) estimated that there are over 100,000 plant diseases] seemingly offer untapped reservoirs of potential controls for these plants. Advantages of using plant pathogens to control waterweeds would be: (*a*) control applications would presumably require minimal technology and, if successfully established, the pathogen in theory would be self-maintaining, (*b*) the overwhelming number of different plant-pathogenic species from which to choose offers an unmatched versatility in selecting a specific biological control, (*c*) virtually none can attack man or his animals, therefore providing an important advantage over the use of various animals such as snails, which may harbor chordate pathogens, (*d*) plant pathogens, although often killing individuals in a given population, would not be expected to cause the extermination of a species. This attribute is important when considering that the total eradication of one aquatic weed species, such as the water hyacinth, is likely to create an ecological void that in turn may allow a population explosion of a different, more serious species such as hydrilla.

The use of plant pathogens is not without its hazards. Any study undertaken to introduce or test plant pathogens in infested areas must be done with extreme care. The spectacular decline of eelgrass (*Zostera marina*) along the northeastern coast of the United States and in European coastal areas in the 1930s (59, 81) graphically illustrates the potential for destruction that diseases present to plant communities in an aquatic environment. If such a disaster can befall a plant as beneficial as this, we must assume the possibility of the occurrence of a similar event on noxious aquatic plants. This latter event would be of great benefit to man and the possibility of its artificial induction should be seriously considered.

Emersed aquatic plants are probably no less susceptible to plant pathogens than terrestrial plants. In fact, some aquatic plants may have pathogens in common with terrestrial relatives. Numerous viruses, for example, are known to infect the amaranthaceous *Gomphrena globosa* (79), and presumably many of them will be capable of also infecting the related alligatorweed. However, most aquatics are taxonomically unique, having few, if any, terrestrial relatives. Despite their ubiquity throughout the earth's waterways, aquatic plants account for no more than 1% of the known species of angiosperms and 2% of the pteridophytes. Of the 33 families listed by Sculthorpe (66) as consisting more or less exclusively of hydrophytes, 30 have fewer than 10 genera, 17 of these are monogeneric, and 3 are monotypic. Only two families have more than 200 species. Thus, host-specific pathogens such as the rusts and smuts, although perhaps more difficult to locate on these plants, may be ideal as biocontrols since they would not be expected to infect nontarget plant species.

Plant pathogens are certainly known to occur in aqueous situations. Nematodes are dependent upon water for their locomotion and survival, and numerous species are to be found in fresh, brackish, or salt waters. Hirschmann (29) cites several reports of *Radopholus gracilis* collected from the roots of such aquatic plants as *Potamogeton, Carex,* and *Phragmites.* That nematodes inflict serious damage to submersed aquatic plants was shown by Smart & Esser (73), who reported that *Aphelenchoides fragariae* inflicted serious damage to *Cabomba, Limnophila,* and other aquatic ornamentals.

Bacteria and fungi are often found in water. Species in the genus *Pseudomonas* are commonly encountered as water inhabitants (8). Among the fungi, Myxomycetes, Ascomycetes, Basidiomycetes, and Fungi Imperfecti all have some aquatic species, and the Phycomycetes have numerous aquatic forms. Sparrow (76) lists the following phycomycete orders as being aquatic: Chytridiales, Blastocladiales, Monoblepharidales, Hypochytridiales, Plasmodiophorales, Saprolegniales, Leptomitales, Lagenidiales, and the pythiaceous Peronosporales. Such zoospore-producing organisms certainly are perfectly adapted to infect submersed plants. Ridings & Zettler (60) implicated a species of *Aphanomyces* as the causal agent of a lethal disease of submersed amazon sword plants (*Echinodorus sp.*) at an aquatic nursery in Florida.

Viruses might be expected to be perpetuated indefinitely in many waterweeds inasmuch as the capacity to produce seed is very much reduced, if not lost, in most vascular aquatics (66); virus-free plants would hence not be forthcoming from this source once plants become infected. Virus vectors can be expected to occur in aquatic environments. The aquatic chytrids, notably *Olpidium brassicae,* are established vectors of such viruses as tobacco necrosis and lettuce big vein (25). Similarly, dorylaim nematodes, species of which are vectors of nematode-transmitted polyhedral-particle viruses (NEPO) and nematode-transmitted tubular-particle viruses (NETU) (11, 25a) are common inhibitors of waterways. Arthropod vectors of viruses, though unlikely to be found beneath the water's surface, could feed and transmit viruses to emergent plant parts. Various aphids have been reported to colonize water plants. *Rhopalosiphum nymphaeae,* a vector of several viruses (34), has been collected from a large variety of aquatic plants including *Marsilea, Potomogeton, Sagittaria, Scirpus, Pistia, Eichhornia, Nuphar, Ceratophyllum, Myriophyllum, Utricularia* (51). Other groups of virus vectors have also been collected from emersed parts of water plants. Silveira-Guido (70) has collected two leafhopper species and an undetermined eriophyid mite from water hyacinths in Uruguay. MacClement & Richards (39a) reported recovering viruses from several aquatic plants (*Lemna minor, Potamogeton crispus, P. pectinatus, Ceratophyllum, Nymphaea*) growing wild at the Royal Botanical Gardens of Hamilton, Ontario.

The Pestiferous Aquatic Plants and Their Diseases

Algae, certain pteridophytes, and various monocotyledonous and dicotyledonous angiosperms all have representatives that have become pestiferous as waterweeds.

Algae.—The most significant algal pests are to be found among the Cyanophyta, Chlorophyta, Charophyta, Euglenophyta, and Chrysophyta. Populations of algae can create unsightly and odoriferous scums on water surfaces and interfere with water clarity. Certain pestiferous charophytes such as *Chara* spp. are macroscopic and can impede water flow. Infestations of other algae typically occur as cyclic "blooms" that tend to materialize within relatively brief periods of time as a result of sudden infusions of nutrients. Although algae and higher plants coexist under normal conditions, population explosions of one tend to occur at the expense of the other, due to competition for nutrients and light. The competition was demonstrated by Hasler & Jones (27), who showed that algae did not develop as well in ponds containing large populations of *Elodea canadensis* and *Potamogeton foliosus* as in identical ponds without these vascular hydrophytes. Conversely, algae can suppress the development of vascular plants.

Plant pathogens infect algae as they do higher plants, but only rarely have they been considered in controlling algal blooms. Various workers have shown blue-green algae to be susceptible to lysogenic viruses closely resembling those affecting bacteria (64), and several have been studied in the United States (62, 64), India (72), Israel (49), Scotland (18), and the Soviet Union (24, 45). Safferman & Morris (63), Daft, Begg & Stewart (18), and Cannon, Shane & Bush (12), have suggested that under natural conditions some cyanophytes that seldom form blooms are prevented from doing so by being continually checked by high populations of viruses, or cyanophages. Much less appears to be known about bacterial pathogens of algae, although Stewart & Brown (77) reported that a species of *Cytophaga* lysed certain blue-green and green algae. Nematodes might be considered potential biocontrols of algae, for numerous marine and fresh water species feed on them. *Dorylaimus ettersbergensis*, was observed by Hollis (30) to consume cells of green and blue-green algae. Aquatic fungi also have potential for controlling algae. Sparrow and others (13–15, 21, 76) list various algae that are hosts of aquatic phycomycetes; among them are species in 13 genera of Cyanophyceae, 67 Chlorophyceae, 4 Characeae, 7 Xanthophyceae, 1 Eugenophyceae, and 30 Bacillariophyceae. Among the phycomycete genera with species infecting algae are *Olpidium*, infecting species in over 25 algal genera (76) and *Aphanomyces*, pathogenic to species of *Mougeotia, Nitella, Spirogyra, Vaucheria*, and *Zygnema* (65).

Vascular Aquatic Weeds.—Whereas algae are principally aquatic forms of life, and have been so since Precambrian times, the progenitors of today's vascular aquatics are descendents of terrestrial plants (66). Water plants are by no means a homogeneous assemblage, as the transition from a terrestrial to an aquatic existence was made repeatedly through time by many different plant groups. Some, like the Isoetaceae and Nymphaeaceae, represent lines that made this transition relatively long ago; others apparently have become aquatic much more recently and still closely resemble their relatives on land.

Vascular aquatic plants can be categorized as either emergent or submergent, with the former the most conspicuous but not necessarily the most troublesome. Emergents may be subdivided into free-floating forms that drift about over the water surface, and anchored emergents attached to the substrate by their roots.

Free-floating plants are raft-like with buoyant foliage and submersed pendent roots. They establish themselves uniformly over waterways and can readily adjust to fluctuations in water levels, but are vulnerable to the caprices of winds and currents and hence are generally restricted to sheltered habitats. They multiply with great rapidity and soon cover the surface of the water, rendering the waterbody meadow-like in appearance.

The most significant of all free-floating plants as weeds are the water hyacinth, water lettuce, and salvinia (*Salvinia auriculata*), all of which are now pantropical. The large stoloniferous forms such as the water hyacinth are generally considered to be of greater significance than diminutive forms such as salvinia.

Water hyacinth is infamous for its prodigious growth rate. In one study, it was calculated that 10 individuals were capable of giving rise to 655,360 plants in a single 8-month growing season (52). This plant is an indigene of Latin America but is now to be found throughout the tropics and subtropics.

Apparently the first disease recorded on water hyacinth was a rust, *Uredo eichhorniae*, reported from the Dominican Republic by Ciferri & Fragoso (17) in 1927. The following year Ciferri (16) reported the occurrence of the smut *Doassansia eichhorniae* from the same area. Neither of these diseases has been studied as biological-control agents.

In 1932, a species of *Fusarium* was reported on water hyacinths from India by Agharkar & Banerjee (1). The fungus induced reddish brown spots on the petioles followed by chlorosis and withering of affected leaves. Interestingly, even at this early date these authors considered utilization of the disease for biological control, as evidenced by their final conclusion: "The infection takes place readily but owing to the high resisting power of the plant, the disease makes very slow progress. From this it may be inferred that this fungus cannot be regarded as a possible remedy against the spread of water hyacinths." The causal agent of this disease was later identified as *Fusarium equiseti* by Banerjee (2). Snyder & Hansen (75) have reduced this species to synonymy with *F. roseum*. This latter species has been found by Rintz & Freeman (61) affecting water hyacinth in Florida.

Recently, a concerted research program on biological control of aquatic weeds was begun at the Commonwealth Institute of Biological Control, Indian Station, in Bangalore. They have investigated the diseases of various aquatic plants in addition to water hyacinth. In addition to the search for new diseases, they have considered the biological-control potential of some previously reported diseases. According to Nag Raj (46), *Cercospora piaropi,* first reported by Thirumalachar & Govindu (78), causes negligible damage and appears of little value in reducing the vigor of hyacinth populations. However, *Cephalosporium eichhorniae* described by Padwick (50) may be of some value. Freeman, Rintz & Zettler (unpublished) have noted a similar leaf-spot disease damaging water hyacinth in Trinidad, Puerto Rico, El Salvador, Louisiana, and Florida, but its relation to that described by Padwick remains to be determined.

Nag Raj & Ponnappa (47) reported in 1967 the occurrence of the *Rhizoctonia* stage of *Corticium solani* on water hyacinth. This presumably is the same *Rhizoctonia solani*-induced blight that had previously been reported by Padwick (50). A closely related fungus, *Hypochnus sasakii,* from rice was found to affect water hyacinth in Taiwan (41) as early as 1933. More recently, Freeman & Zettler (22) reported the isolation of a strain of *R. solani* from anchoring hyacinths (*Eichhornia azurea*) in Panama that can severely affect and kill water hyacinths. The organism produces abundant sclerotia which will survive submersed without loss of virulence for at least 9 months (22). Nag Raj (46) considered *R. solani* to have little use for biological control due to its broad host range, although introducing this pathogen into an aquatic environment would not necessarily increase the already present inoculum in soils around crop plants. The real damage may well be its effect on beneficial aquatic plants. In 1928 Bourn & Jenkins (7) attributed the destruction of large areas (total of about 300 square miles) of aquatic food plants for ducks in Virginia and North Carolina to a physiological strain of *R. solani.* Species of plants affected were *Potamogeton pectinatus, P. perfoliatus, Ruppia maritima, Vallisneria spiralis,* and *Najas flexilis.*

Additional pathogens recorded on water hyacinth by the Indian group include *Myrothecium roridum* var. *eichhorniae* (55), *Marasmiellus inoderma*

(46), *Alternaria eichhorniae* (48), *Helminthosporium*
Curvularia clavata (58). Of these, *M. roridum* var. *eichhorniae* and *A. eichhorniae* appear the most promising for use in biological control. However, Ponnappa (55) believes that the wide host range of *M. roridum* precludes its use. Nag Raj & Ponnappa (48) consider that the narrow host range of *A. eichhorniae,* coupled with the ability of the pathogen to produce a toxin, warrants biological control trials with it.

Although widespread, water lettuce does not rank with water hyacinth as an impediment of waterbodies. It is a relatively fragile plant, prone to damage by natural forces, and hence is most commonly found on relatively placid waterbodies (31, 84). In large exposed waterways such as Guatemala's Lake Izabal, this weed is destroyed by wave action despite continued infusions of fresh plants from nearby tributaries (28). The main hazard from water lettuce is that it harbors the *Mansonia* mosquito which, as noted earlier, is a vector of human diseases.

Water lettuce is affected by *Cercospora* sp. (47), *Sclerotium rolfsii* (47), and *Phyllosticta stratiotes* (56) in India. However, the usefulness of these pathogens for biological control has not been explored. Recently a virus reputedly transmitted by *Rhopalosiphum nymphaeae* has been reported from Africa (53). However, dasheen mosaic virus, an aphid-transmitted virus of several aroids (87), including the aquatic ornamental *Cryptocoryne cordata,* did not infect water lettuce seedlings in Florida (Hartman & Zettler, unpublished).

Salvinia is a diminutive free-floating pteridophyte with pubescent oval leaves about 1 cm long. This species is a native of the neotropics but has become of considerable significance in several areas of the paleotropics, particularly in Ceylon and in Africa's Lake Kariba (31, 66).

Salvinia is affected by *Myrothecium roridum* in India (58). Presumably the use of this pathogen for salvinia control would be objectionable on the same grounds as water hyacinth, i.e., broad host range of the fungus. Also, a cyclic die-back of salvinia associated with species of *Alternaria* and *Spicariopsis*

Anchored emergents are normally firmly rooted to the substrate and are thus more limited in habitat than their free-floating counterparts. These plants tend to be restricted to relatively shallow bodies of water, ditches, or along shorelines. However, when they grow profusely, their roots can become tightly interwoven into mats that can float as self-supporting islands, or sudds.

The anchored emergents are an arbitrary assemblage composed of several different taxa, among which are species of Amaranthaceae, Cyperaceae, Gramineae, Polygonaceae, and Typhaceae. These plants are distributed throughout the world and are conspicuous features of the aquatic environment. Sawgrass (*Cladium jamaicensis*), for example, is the dominant plant of the Florida Everglades (84). Although frequently beneficial, they are considered to be pests when they impair navigation, hinder hydroelectric projects, or interfere with fishing or agriculture.

Alligatorweed merits special attention as an anchored emergent. Native to South America, it can now be found in tropical and warm-temperate locales throughout the Western Hemisphere, and in certain areas in the Eastern Hemisphere. It has remarkable versatility, being able to grow equally well in a mat over open water, buoyed by hollow stems, or as a terrestrial plant rooted in soil in a relatively dry field. In Louisiana, this plant, although a weed to most people, is favored by cattlemen as convenient fodder in pastures (40).

Alligatorweed is subject to several diseases, none of which appear to have been investigated as control for this plant. It has been reported to be affected in Louisiana by *R. solani* (19, 71), *Heterodera marioni* (54), and *Anguillulina dihystera* (54). In addition, alligatorweed plants affected by a stunting disease, believed to be virus induced, have been found in the Ortega River of Florida (Hill & Zettler, unpublished). *Alternanthera sessilis*, a near relative of alligatorweed, is affected by *Corticium solani* (47), *Colletotrichum capsici* (56), *Glomerella cingulata* (47, 57), *Phoma* sp. (56), and *Albugo bliti* (57) in India. Goodey, Franklin & Hooper (23) list *Pratylenchus coffeae, Meloidogyne incognita,* and *M. javanica* as infecting several additional species of *Alternanthera*. In addition, Arthur (1a) reported a rust *Uredo nitidula*, infecting alligatorweed plants in Guatemala.

Diseases have also been reported on other anchored emergents. Two of three *Panicum* species of most concern in the United States [maidencane (*P. hemitomum*) and paragrass (*P. purpurescens*)] have had 9 and 7 pathogens reported to attack them, respectively. Eighteen diseases have been reported for the common reed (*Phragmites communis*), three for southern wild rice (*Zizoniopsis miliaceae*), and more than twenty for the grass-like cattails (*Typha* spp.) (32). Other species have not been as thoroughly investigated; no diseases are reported for such conspicuous and important species as torpedograss (*Panicum repens*), water paspalum (*Paspalum fluitans*), and sawgrass (32).

Despite the presence of several pathogens affecting anchored emergents, their use for biological control presents some unique problems. Indeed, in this case biological control may not be feasible because this group of plants is not totally noxious. Certainly we could ill afford to risk the destruction of important waterfowl food plants such as maidencane, southern wild rice, and giant reed. Of no less importance is the use of paragrass as forage in warmer climates and *Typha* spp. as valued ornamentals in aquatic gardens. Thus, it appears that biological control of such anchored emergents as the aquatic grasses may require a degree of specificity in phytopathogens difficult to attain.

Submersed weeds are probably the most serious of all types of aquatic vegetation, and the most difficult to control because, being submersed, they cannot be readily sprayed with herbicides nor can they be easily removed with machines (31). Furthermore, they are immune to predation by many organisms unable to exist under water. The most noxious species have weak fibrous stems incapable of self support, and, except for their flowers, are unable to survive for even brief periods out of water. Although roots are formed, they are of minimal significance as anchoring devices. These plants grow indeterminately and as the stems elongate, they branch in every direction to create an impenetrable labyrinth of green strands capable of converting an unobstructed body of water into a virtual sargasso sea.

Numerous highly specialized species of submersed aquatic plants are regionally notorious for their ability to invade new sites rapidly. Most often cited water pests are as follows: *Ceratophyllum* (Ceratophyllaceae), *Myriophyllum* (Haloragaceae), *Utricularia* (Lentibulariaceae), *Najas* (Najadaceae), *Cabomba* (Nymphaeaceae), *Potamogeton* (Potamogetonaceae), and *Anacharis, Egeria, Elodea,* and *Hydrilla* (Hydrocharitaceae) (31, 66, 84). Because of their beauty, various members of this group have been transported throughout the world as ornamentals, and in many instances have become established in new locales by aquarium plant dealers who introduced them into public waters to be harvested as needed.

Hydrilla, an old-world native introduced into south Florida in 1958–1960, currently ranks second only to water hyacinth as an aquatic pest in that state (5, 44). The rapid spread of hydrilla in Florida is reminiscent of the spread of its new-world relative, Canada elodea, in Europe.

Eurasian watermilfoil is another equally widespread weed in fresh and brackish waters. In the United States, this old-world native has become a nuisance of particular prominence within the last 10-20 years, infesting thousands of acres in the Chesapeake Bay, Tennessee Valley, and Currituck Sound.

In comparison to the diseases reported on free-floating and emersed plants, there is a paucity of reports concerning diseases of submerged plants. This is probably due to lack of investigation rather than absence of diseases affecting these plants. Two disorders, "Northeast Disease" and "Lake Venice Disease" (3, 4), were considered to be causes of a sudden decline in distribution and abundance of Eurasian watermilfoil populations in the Chesapeake Bay in the mid 1960s. No causal agents were ever established for them. Also, milfoil plants did not become infected when inoculated with alfalfa mosaic virus, tobacco mosaic virus, tobacco ringspot virus, potato virus X, or potato virus Y (3). For several years, personnel of the Institute for Plant Protection in Beograd, Yugoslavia, have investigated diseases affecting milfoil under a project supported by PL 480 funds. This group has isolated a variety of fungi from declining milfoil plants and several of them have been reported to be pathogenic to milfoil seedlings. Pathogens reported are: *Alternaria* sp., *Articulospora tetracladia, Botyris* sp., *Dactylella microaquatica, Flagellaspora stricta, Fusarium acuminatum, F. oxysporium, F. poae, F. roseum, F. sporotrichoides, F. tricinctum, Mycelia sterilia, Sclerotium hydrophyllum, and Stemphylium* sp. (37). The nematode, *Ditylenchus dipsachi tobaensis,* has been found on *Myriophyllum verticillatum* (23). Whether any of these can be used on a practical scale for milfoil control remains to be determined.

We have been unable to find reports of diseases affecting species of *Hydrilla, Egeria, Anacharis,* or *Elodea,* although we believe that diseases do affect these hydrocharitaceous plants.

Conclusions

The plant pathologist may be guilty of tunnel vision by directing most of his research efforts towards terrestrial plants and ignoring the aquatics. Our almost nonexistent research efforts with aquatic plants, particularly the submersed forms, certainly do not reflect their ubiquity and their importance as noxious weeds, food for wildlife, and ornamentals. The lack of information on diseases of aquatic plants is obviously not related to the nonexistence of pathogens. When investigations have been undertaken, pathogens have been found, and in some instances shown to inflict great damage to their hosts. That we have ignored diseases of water plants for so long is surprising. Vascular aquatic plants, having evolved from terrestrial ancestors, adapted themselves in amazing ways to survive in water. It would be intriguing to determine how their pathogens have become adapted for such an existence. Aside from simple curiosity, it may be that our discipline holds the most important key in controlling water weeds. This is reason enough for conducting research in this long-neglected field.

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