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Potential Use of Insect Biocontrol Agents for Reducing the Competitive Ability of *Hydrilla verticillata*

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit #33117. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC), Waterways Experiment Station (WES), Vicksburg, MS, under the purview of the Environmental Laboratory (EL). Funding was provided under the Department of the Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology (CAPRT), Dr. John Barko, Director. Mr. Robert C. Gunkel, Jr., was Assistant Director, CAPRT. Program Monitors during this study were Mr. Timothy Toplisek and Ms. Cheryl Smith, HQUSACE.

Principal Investigator for this work unit was Dr. Michael J. Grodowitz, Aquatic Ecology Branch, Ecosystem Research Division (ERD), EL, WES. This report was reviewed by Drs. Judy Shearer and Alfred Cofrancesco. Drs. Michael J. Grodowitz, Robert Doyle, and R. Michael Smart prepared this report.

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1 Introduction

Aquatic plants are natural components of shallow water and can significantly impact, both positively and negatively, the habitat in which they are found. Whether the assemblage of aquatic plants can significantly enhance or detract from the desired uses of shallows is highly dependent on the kind and quantity of the species present. Most aquatic plant communities significantly benefit the environment by improving water clarity (by preventing sediment resuspension and removing excess nutrients) and providing high-quality habitat for invertebrates, fish, birds, and other organisms (Scheffer 1998).

Unfortunately, some species of aquatic plants grow so profusely that, rather than benefiting the ecosystem, they interfere with water resource use and cause significant environmental problems. Widespread problems associated with aquatic plants are usually caused by the presence of canopy forming, nonnative species specialized for growth in disturbed environments (Smart and Doyle 1995). Nuisance aquatic species such as *Hydrilla verticillata* (hydrilla) are characterized by development of very high levels of plant biomass and the formation of dense, thick canopies or mats at the water surface. This growth characteristic results in management problems at high-use locations such as boat ramps, channels, water intakes, or swimming areas (Langeland 1990). In addition, this growth characteristic has the potential for causing ecological and water quality problems (Smart and Doyle 1995). Dense surface canopies prevent the penetration of light into the water and effectively shade out other species which might grow beneath. In addition to obstructing light penetration, this canopy interferes with the transfer of oxygen from the atmosphere to the water and often results in depleted oxygen conditions (Honnell, Madsen, and Smart 1993).

In contrast to the deleterious impacts of hydrilla, native plant communities such as those dominated by *Vallisneria americana* (vallisneria) usually provide the desired benefits of an aquatic plant community but rarely present management or ecological problems. The difference in desirability between hydrilla- and vallisneria-dominated plant communities centers on the enormous differences in their growth characteristics. Hydrilla produces high levels of shoot and leaf biomass that are concentrated at or near the water surface (Figure 1). Very rapid growth rates (up to 2.5 cm per day), tolerance of poor growing

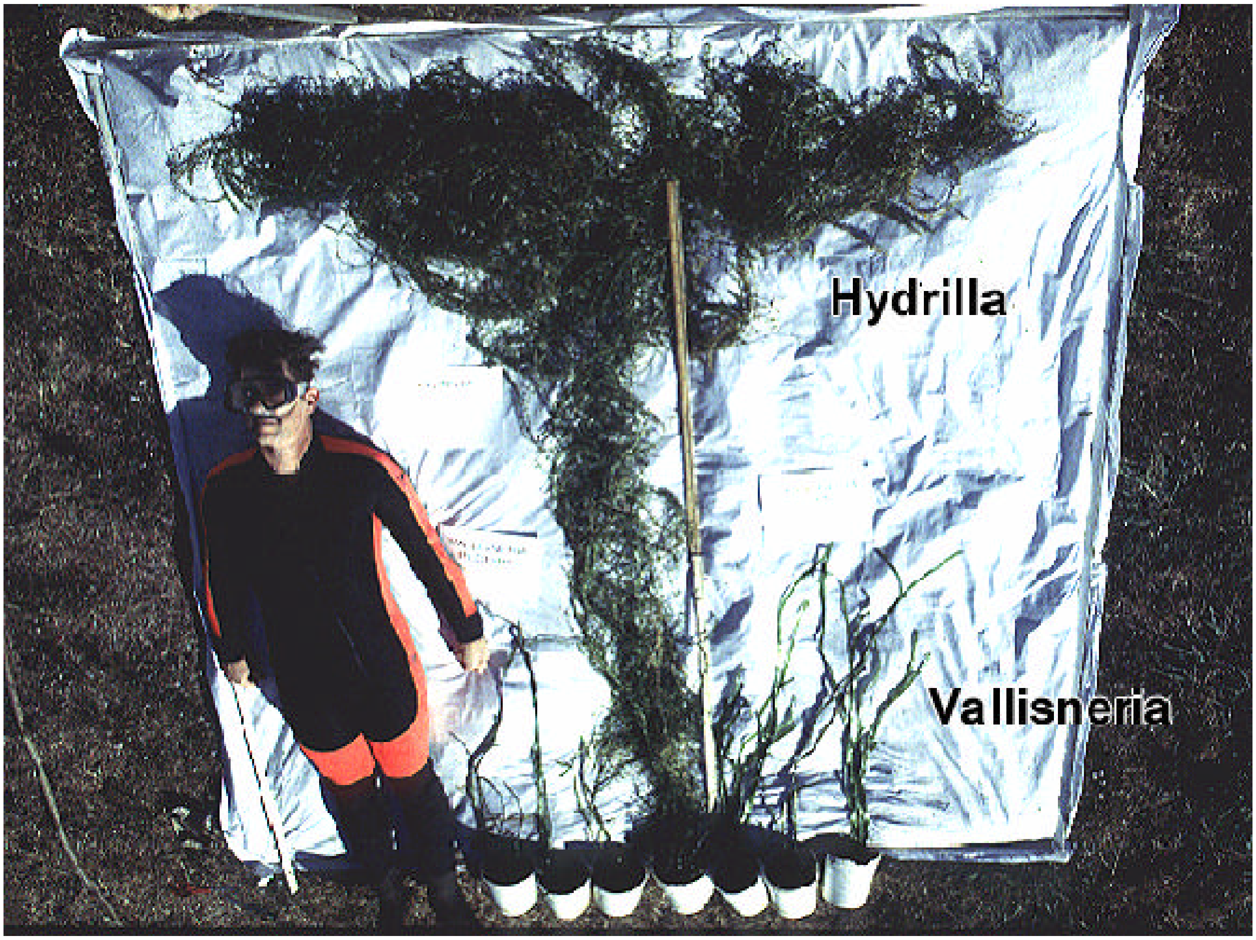

Figure 1. Vegetation harvested from tank plant competition experiment showing differences in growth characteristics between hydrilla and vallisneria. Note how hydrilla forms a dense canopy which can effectively shade out plants in deeper water

conditions, and rapid spread through stem fragmentation and turion formation (Smart, Barko, and McFarland 1994) allow hydrilla to rapidly colonize new sites. This plant is also adapted to produce large number of tubers within the sediments. Such tuber banks in the sediments allow the population to quickly recover following winter diebacks or management efforts to control the plants.

Vallisneria, on the other hand, is usually a desirable component of an aquatic plant community. The species is highly valued as excellent waterfowl food and for providing good habitat for invertebrates and fish (Korschgen and Green 1988). Vallisneria grows more slowly than hydrilla and places more energy into an extensive root system rather than a surface canopy (Figure 1). Vallisneria may be less tolerant of large-scale disturbances to the environment than hydrilla, even though it is capable of withstanding moderate disturbances to the environment (Davis and Carey 1981), surviving under somewhat turbid conditions (Secchi depths 1 to 6 m) (Davis and Brinson 1980), and persisting in fluctuating riverine environments such as the Upper Mississippi River System.

2 Plant Competition

When grown together, individual plants may compete with each other for essential resources such as light, inorganic carbon, and nutrients such as nitrogen and phosphorus. Such competitive interactions are known as intraspecific competition. Interspecific plant competition occurs among individuals of differing species growing in close proximity to each other. Since the aquatic plant community can enhance or degrade the shallow-water environment depending on the dominant species present, the outcome of such competitive interactions are of considerable interest to reservoir managers and users of the water resource.

The competitive interactions between nuisance and desirable species have been studied under a variety of conditions, and the outcome of that competition depends on environmental conditions (McCreary Waters, Barko, and McFarland 1993; Smart, Barko, and McFarland 1994) as well as the degree of preemption which one species may exert over the other (Smart 1993; Smart, Barko, and McFarland 1994). In many cases, if the desirable plants can be established and allowed to preempt the environmental resources, the negative impacts of the nuisance species are dramatically reduced (Doyle and Smart 1998).

Considerable information exists on the competitive interactions between hydrilla and vallisneria. Under most conditions, preemption appears to be a major factor, which could tilt the outcome of the competition in favor of the desirable species (Smart, Barko, and McFarland 1994). If vallisneria is allowed to colonize an area prior to hydrilla invasion, the result of the competitive interactions usually favors vallisneria. The ability of a competitive species such as vallisneria to resist an attempted invasion by another species depends on the degree to which it has preempted the limiting resources of the environment (Smart 1993). If vallisneria is allowed a suitable head start, it is able to maintain its dominance over the plant community and hydrilla is relegated to a relatively minor component of the mixture. Unfortunately, this situation rarely occurs in reservoirs where weedy exotics are usually the first colonizers following the creation of the reservoir. Because vallisneria has relatively slow rates of growth and dispersal, it usually does not colonize and dominate an area before hydrilla becomes problematic.

Under the more common situation where hydrilla and vallisneria both attempt to colonize a nonvegetated area at the same time, hydrilla is heavily favored (Smart 1993; Van, Wheeler, and Center 1998). The rapid growth rate and prolific ability to spread via fragmentation make this type of competition relatively easy for hydrilla. Tank studies illustrate this fact. Figure 1 shows the results of hydrilla and vallisneria planted at the same time in a large tank of water. Hydrilla quickly grew to the surface and spread out to form a dense canopy. The vallisneria plants beneath were severely hampered by this exuberant early growth of hydrilla.

Effects of Herbivores on Plant Competition

Three attributes of hydrilla explain its dominance in many reservoir ecosystems- a very effective means of dispersal, rapid growth rate, and the formation of a dense, continuous canopy at the water surface (Smart 1993; Smart, Barko, and McFarland 1994). However, in its native range, i.e., Asia, Indonesia, and Australia, hydrilla rarely, if ever, becomes dominant in most shallow water situations (personal observations, Dr. Michael Grodowitz and personal communication, Dr. Gary Buckingham, Ms. Chris Bennett, and Dr. Judy Shearer).[1] Typically, it resides as one species in a diverse assemblage of submersed macrophytes (Figure 2) or as small, single plants found scattered throughout a specific area (Figure 3). Rarely is it observed as a dense monotypic infestation in its home range.

Unfortunately, the reasons for such a lack of dominance of hydrilla in its native range are largely unexplored. Abiotic factors, such as climate and sediment are important factors to consider when determining how hydrilla grows in specific areas. However, in most cases habitat type and climate of the new area are highly suitable and similar to the native range and hence, do not appear to explain the apparent disparity in the growth characteristics of hydrilla between the two regions.

One of the major differences in plants found in their native range and in the new area of introduction is the presence of a large and typically diverse assemblage of herbivores and pathogens present on the plant in the native range. *Melaleuca quinquenervia* is an excellent example where over 400 different herbivores have been found feeding on it in its native range (Balciunas, Burrows, and Purcell et al. 1992). Major differences in its growth characteristics have been observed; in its native range melaleuca is a relatively small tree with only limited canopy, stand density, and leaf density. Also, only small numbers of seedlings are observed (Figure 4). Contrast this to its growth in the United States

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[1] Personal communications, 1995, Gary Buckingham, U.S. Department of Agriculture, ARS, Gainesville, FL; Judy Shearer, U.S. Army Engineer Waterways Experiment, Vicksburg, MS; Chris Bennett, University of Florida, Gainesville, FL.

Figure 2. East Lake near Wuhan, China, showing large infestation of submersed vegetation. At first glance, it would appear to be a monoculture, but in fact, it was a mixed assemblage including plants in the genera *Potomogeton*, *Myriophyllum*, *Najas*, *Vallisneria*, and *Ceratophylum*. Hydrilla made up only a minimal portion of the infestation

where the trees are vastly larger, have higher leaf and stand densities, and a large number of seedlings are ubiquitous (Figure 5). Another example is Australian pine where habitat and climatic conditions are similar between its native range (i.e., Australia) and its United States distribution. In its native range, Australian pine is a relatively small tree with only limited number of leaves, and minimal formation of a dense canopy (Figure 6). However, major differences are observed in its growth characteristics in the United States where Australian pine reaches tremendous size, has large number of leaves, and forms a full canopy (Figure 7). These differences in growth are apparently a result of the large herbivore/plant pathogen assemblage impacting it in its native range.[1]

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[1] Personal communication, 1996, D. J. Balciunas, U.S. Department of Agriculture, ARS, Ft. Lauderdale, FL.

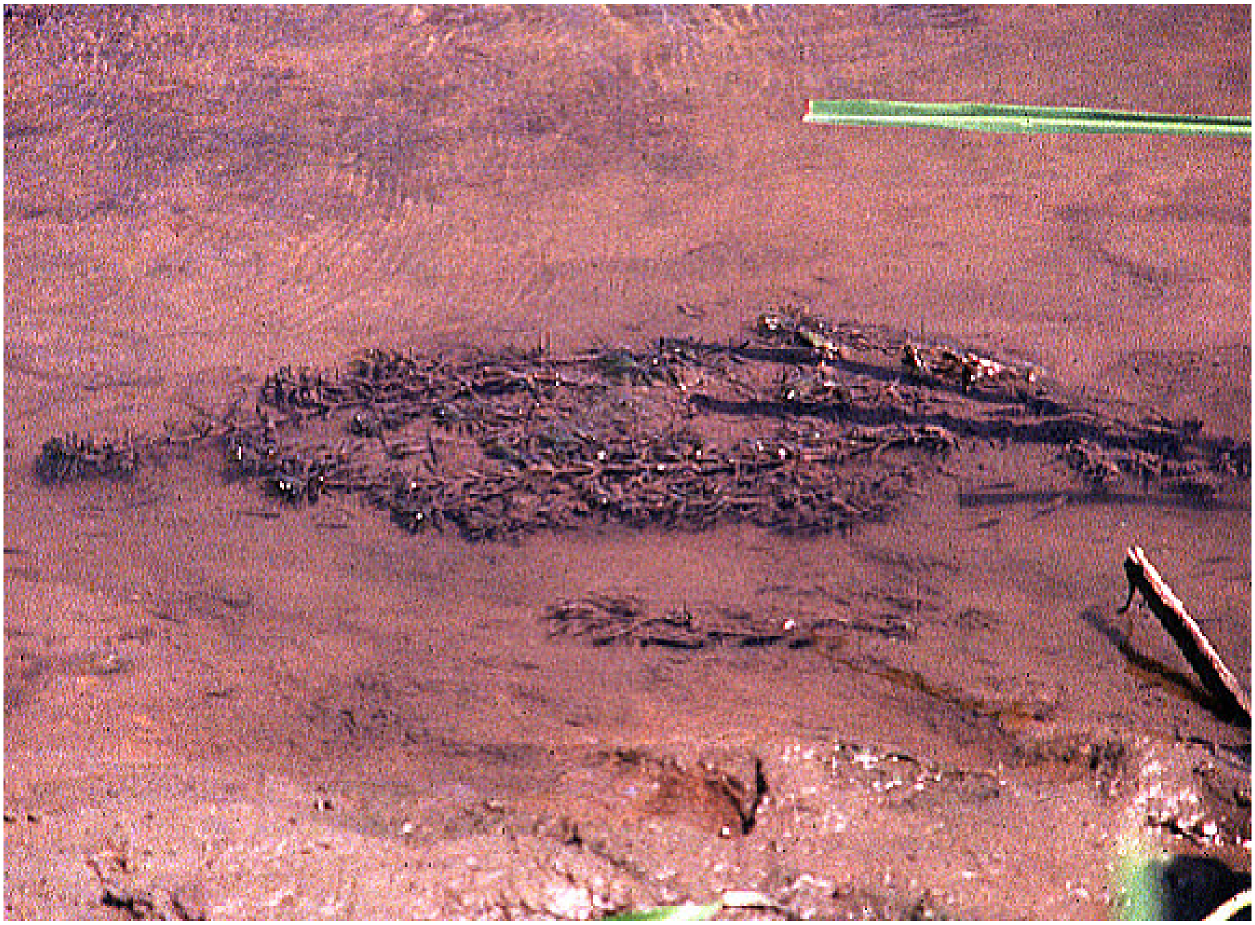

Figure 3. Hydrilla as it typically appears at many areas in its home range in China (near Shenyang). Note that the plants are small and found only in scattered bunches not covering the entire water body

In natural systems, herbivory is largely responsible for keeping plant abundance limited and at reasonable levels (Harley and Forno 1992) and invertebrate grazing, typically by insects, is probably one of the more important regulatory factors (Huffaker et al. 1984). This type of effect, where insect herbivory directly impacts a target species, has long been recognized and forms the basis for the release of host-specific insects for biological control (Harley and Forno 1992). Various published accounts have documented significant impacts by insect herbivores on several exotic weed species, the majority of which are associated with biological control projects (Julien 1987). These include the alligatorweed flea beetle that rapidly impacts alligatorweed, as well as biological control targets of *Lantana*, *Opuntia*, and diffuse knapweed. The impact of gypsy moth on various hardwoods across the eastern United States is also well documented (Baker 1972). In many of these cases, insect herbivory impacts plant vigor, which leads directly to declines in the plant population. Herbivory is apparently the main factor responsible for the declines.

Figure 4. Melaleuca stand near Port Douglas in Queensland, Australia. Note the low density of trees, their minimal size, limited numbers of seedlings, and lack of any significant canopy

Some authors have suggested that invertebrate grazing which results in direct plant mortality is probably the exception rather than the rule (Oksanen 1990; Louda, Keeler, and Holt 1990; Crawley 1989). These authors argue that, in most cases, sustained feeding results in a lose of plant vigor, though not to the extent that significant plant mortality is observed, but rather that the competitive advantage of the damaged plant is decreased. This change in plant competitiveness ultimately leads to changes in plant population size and distribution. Examples of this include waterhyacinth/*Neochetina* system (Center 1987, 1994; Center and Van 1989), Canada thistle/*Cassida rubignosa* system (Ang et al. 1994), Hydrilla/*Hydrellia pakistanae* system (Van, Wheeler, and Center 1998), *Rumex*/*Gastrophysa viridula* system (Bentley and Whittaker 1979), and the *Trifolium*/*Dactylis*/*Derocerus* system (Cottam et al. 1986). In all cases, the apparent impact of invertebrate herbivores on the target species was significantly greater in the presence of a capable plant competitor. To complicate matters further, the amount of plant productivity as influenced by nutrient levels may also influence the impact of herbivory (Oksanen 1990). Oksanen (1990) indicated that in very productive areas, high levels of predators would limit the

Figure 5. Melaleuca infestation on Lake Okeechobee, Florida. Note the high density of trees, large tree size, wide range of tree ages, and formation of a full and dense canopy

abundance of herbivores, and in barren areas numbers of herbivores would be naturally low and most would occur as transients. The largest impact is predicted in areas with intermediate productivity because the moderate herbivore densities would greatly impact the relatively meager production of vegetation.

Figure 6. Australian pine near Mission Beach in Queensland, Australia. Note the small size of the tree and minimal amounts of leaves and branches

Figure 7. Australian pine located near Fort Lauderdale, FL. Note the large stature of the tree and high amounts of leaves and branches

3 Hydrilla Insect Biocontrol Agents

In 1987, the first of four host-specific insect agents were introduced for the management of hydrilla (Center et al. 1997). The first species, the leaf-mining fly, *Hydrellia pakistanae*, was first introduced into Florida and subsequently in Louisiana, Alabama, Georgia, Texas, and California. Its distribution has expanded considerably, now extending throughout the Florida peninsula, upward into the Florida panhandle and Georgia mainly on Lake Seminole, north and west into Alabama, and throughout many locations in eastern and southeastern Texas. Apparently, direct impact to hydrilla by *H. pakistanae* has been observed at several locations mainly in northern Alabama and Texas (Grodowitz, Center, and Snoddy 1995, Grodowitz et al. in preparation), but long-term monitoring for impact has been limited. In those areas sampled, *Hydrellia* spp. population levels and associated damage have been low. Unfortunately, the factors accounting for such low populations have not been determined or quantified but have been suggested to include high levels of parasitism, plant nutritional quality, and other forms of predation (Wheeler and Center 1996).[1] The other three insect agents that were introduced have had limited, if any measurable success. These include the closely related leaf-mining fly *H. balciunasi* (Grodowitz et al. 1997), the tuber feeding weevil *Bagous affinis*, and the stem-feeding weevil *B. hydrillae* (Grodowitz, Center, and Snoddy 1995). Of these three species, the only agent to become established has been *H. balciunasi*, but expansion in distribution and population size for this species has been severely limited.

Immature *Hydrellia pakistanae* feed on the internal cellular material of the leaves (Buckingham, Okrah, and Thomas 1989). Each larva is capable of damaging from 9 to 12 leaves during the three larval instars. Pupation occurs within the hardened last larval instar cuticle, which is termed the puparium. After emergence occurs, the adult opens the top of the puparium and escapes in an air bubble whereby it floats to the water surface. The adult is small, roughly 1.5 mm in length and begins ovipositing almost immediately on any type of emergent vegetation. Each female is capable of producing approximately 100 to 200 eggs

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[1] Personal communication, 1997, Jim Cuda, University of Florida, Gainesville.

during its active reproductive period. Adults are short-lived surviving on average only about 10 days. Developmental times are dependent on temperature and take, on average, about 20 days from egg to adult at 27 EC. While observations and actual quantification of field damage for *H. pakistanae* is limited, several reports have documented that sustained feeding by *H. pakistanae* produces large areas of cleared and browning leaves on large portions of the stems. This is turn leads to increased numbers of broken and floating stem pieces on the surface. When damage approaches 25 to 35 percent, the canopy appears to collapse, leaving large holes in the surface canopy (Grodowitz, Center, and Snoddy 1995, Grodowitz et al. in preparation).

Integrated Control of Hydrilla: Insect Biocontrol and Plant Competition

The introduction of a host-specific insect herbivore may minimize the vigor of hydrilla by reducing its growth rate and productivity and ultimately creating gaps within the surface canopy. This may provide an opportunity for native species to effectively compete with hydrilla (Van, Wheeler, and Center 1998). Based on short-term studies (16 weeks) conducted by Van, Wheeler, and Center (1998), high levels of *H. pakistanae* herbivory (30 to 100 insect larvae per hydrilla plant) produced sufficient insect herbivory to completely defoliate the hydrilla shoots and prevent the formation of a surface canopy. Under those conditions, the early competitive advantage exhibited by hydrilla apical stem fragments planted along with individual rosettes of vallisneria was eliminated. However, additional experiments are needed that examine plant competition and hydrilla insect herbivory over extended time periods (i.e., at least an entire growing season), on well-established plants (not stem fragments and recently transplanted rosettes), and under insect population levels more reflective of field establishment conditions. In addition, procedures and techniques need to be developed that can exploit the benefits of using both plant competition and sustained insect herbivory under field conditions.

Toward this goal, we have initiated a series of experiments to examine the potential for managing nuisance hydrilla infestations by the simultaneous addition of insect biocontrol agents and plantings of native macrophytes. The first experiments have already been initiated and utilize a simple experimental design using large tanks (14,000-L tanks) as the experimental units. For these experiments, hydrilla is being grown in a factorial design with and without vallisneria and with and without the insect herbivore, *H. pakistanae*. The study will be conducted over two growing seasons to allow estimation of the long-term impact of sustained insect herbivory on hydrilla competitiveness, especially during the winter dormancy of both the plant and insect agent.

These studies will subsequently be expanded to small ponds (0.1 ha) to better simulate actual field conditions. For the pond experiments, native plant assemblages (mixtures of various native species) will replace the single species vallisneria as the competitor against hydrilla. Again, we will be assessing the impact of sustained insect herbivory (i.e., *H. pakistanae*) as well as plant competition. The final step in this research will be to utilize the techniques and procedures developed during the tank and pond studies and move into a demonstration phase where native plantings and insect herbivory will be attempted at actual field sites.

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13. ABSTRACT *(Maximum 200 words)*

Three attributes of hydrilla explain the dominance in many reservoir ecosystems: 1) a very effective means of dispersal, 2) rapid growth rate, and 3) the formation of a dense, continuous canopy at the water surface. However, in its native range, i.e., Asia, Indonesia, and Australia, hydrilla rarely, if ever, becomes dominant in most shallow water situations. Typically, it resides as one species in a diverse assemblage of submersed macrophytes or as small, single plants found scattered throughout a specific area. In its home range, rarely is it observed as a dense monotypic infestation. Reasons for such differences in growth characteristics are unknown but may be related to the presence of herbivores that limit the growth and reproduction of the target plant in its home range. The introduction of a host-specific insect herbivore from its native range may minimize the vigor of hydrilla by reducing its growth rate and productivity, and ultimately create gaps within the surface canopy. This report examines the published literature in an effort to understand impacts invertebrate herbivores have in reducing plant growth as well as associated mechanisms of action and impact caused by introduced insect biological control agents on the growth and productivity of hydrilla. Procedures and techniques need to be developed that can exploit the benefits of using both plant competition and sustained insect herbivory under field conditions. Toward this goal, we have initiated a series of experiments to examine the potential for managing nuisance hydrilla infestations by the simultaneous addition of insect biocontrol agents and plantings of native macrophytes. The first experiments have already been established (i.e., summer 1998) and utilize a simple experimental design using large tanks (14,000 L) as the experimental units. For these experiments, hydrilla is being grown in a factorial design with and without vallisneria and with and without the insect herbivore,

(Continued)

14. SUBJECT TERMS

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13. (Concluded).

H. pakistanae. The study will be conducted over two growing seasons to allow estimation of the long-term impact of sustained insect herbivory on hydrilla competitiveness especially during the winter dormancy of both the plant and insect agent. Future experiments include the examination of plant competition and the presence of an insect herbivore in larger more natural systems such as ponds and eventually at actual field sites.