PEST STATUS OF WEED

Waterlettuce, *Pistia stratiotes* L., (Fig. 1) is a floating, herbaceous hydrophyte first recorded from Florida during the 18th century (Stuckey and Les, 1984). It forms extensive mats (Fig. 2) capable of blocking navigational channels, impeding water flow in irrigation and flood control canals, and disrupting submerged animal and plant communities (Sculthorpe, 1967; Attionu, 1976; Bruner, 1982; Sharma, 1984). Waterlettuce is among the world’s worst weeds (Holm *et al.*, 1977). It has been placed on prohibited plant lists in Florida (FDEP, 2000), Louisiana (LDWF, 2000), Mississippi (MDAC, 1997), and Texas (TPWD, 2000), and is considered a noxious species (an invasive species of concern, but not regulated) in South Carolina (SCDNR, 2000) and Delaware (DDFW, 2000).

**Nature of Damage**

*Economic damage.* Waterlettuce is a serious weed of rice crops in other countries (Suasa-Ard, 1976), but has not been reported as interfering with production in the United States. It also can interfere with hydroelectric operations (Napompeth, 1990), but has not done so in the United States. Consequently, direct losses attributable to waterlettuce result primarily from restricted water flow in irrigation and flood control canals in Florida. Unfortunately, the economic costs associated with such damage have not been quantified, but federal and state waterlettuce control operations in Florida cost nearly $650,000 annually (Center, 1994). Other states treat intermittently as nuisance populations arise, but seldom more than a few hundred acres each year. Estimates of expenditures by local agencies and private agricultural interests are unavailable.

Indirect losses accrue when large floating mats interfere with recreational activities such as boating and fishing, but these have not been quantified. Also, several species of mosquitoes that breed on waterlettuce are important vectors of malaria,
encephalitis, and filariae (Dunn, 1934; Bennett, 1975; Lounibos and Dewald, 1989; Lounibos et al., 1990). Outbreaks of St. Louis encephalitis are generally rare; there were 223 reported cases with 13 deaths in Florida in 1990 and nine cases (one death) in 1997 (FDOH, 2000a). Equine encephalitis, also vectored by mosquitoes associated with waterlettuce, affects about 50 horses in Florida each year as well (FDOH, 2000b). Costs associated with these diseases are unknown, and the portion of mosquito control operations directed toward waterlettuce-borne mosquitoes has not been reported.

**Ecological damage.** There are few reports of deleterious ecological impacts associated with *P. stratiotes* infestations and these studies have generally been limited in scope. Sculthorpe (1967), for instance, noted that the intertwined root systems (composed of long adventitious roots arrayed with copious lateral rootlets) of extensive infestations accelerate siltation rates as they slow water velocities in rivers and streams (see also Anonymous, 1971). The resultant degradation of benthic substrates under these infestations has never been studied directly, but accelerated siltation often renders the affected benthos unsuitable as nesting sites for various fish species (Beumer, 1980) and as macroinvertebrate habitat (Roback, 1974). The accumulation of waterlettuce-generated detritus under large infestations only adds to this problem, and likely increases sediment and nutrient loadings much as it does under waterhyacinth mats (Schmitz et al., 1993). Furthermore, Sridhar (1986) reports that waterlettuce can bioaccumulate considerable amounts of heavy metals, so the detritus under some mats could be toxic.

The waters under dense waterlettuce populations in lakes can become thermally stratified (Sculthorpe, 1967; Attionu, 1976), with reduced dissolved oxygen levels and increased alkalinity (Yount, 1963; Attionu, 1976; Sridhar and Sharma, 1983). Prolonged oxygen deficits reduce plankton abundance (Hutchinson, 1975), and cause increased mortality of fish (Ayles and Barica, 1977; Clady, 1977) and macroinvertebrates (Roback, 1974; Cole, 1979). Although these effects likely occur in waterlettuce-dominated systems, they have not been investigated. Finally, Sharma (1984) reported that the evapotranspiration rate over a waterlettuce mat in one African lake was ten-fold greater than the evaporation rate over open water (but see the discussion on this topic and common misconceptions in Allen et al., 1997). However, the implications of this finding for hydrologic cycles in U.S. waterways has not been determined.

**Extent of losses.** In Florida, waterlettuce infests about 2,500 acres of public waterways (after control operations), and a large, but uncounted number of acres of irrigation and flood control canals (Schardt, 1992). Based on the annual costs associated with controlling waterlettuce on at least 10,000 acres of public waterways (Schardt, 1992; Center, 1994), it is reasonable to estimate that total expenditures exceed $1 million annually in Florida. Other states in the eastern United States spend a combined total of less than $100,000/yr on waterlettuce control.

**Geographical Distribution**

Paleobotanical evidence suggests that prior to the Pleistocene the genus *Pistia* extended well beyond its present range into what is now temperate Asia, Europe, and North America (Dorofeev, 1955, 1958, 1963; Friis, 1985; Mai and Walther, 1983; Stuckey and Les, 1984; Stoddard, 1989). Today, waterlettuce is primarily pantropical (Sculthorpe, 1967; Holm et al., 1977), although it also occurs in the Netherlands where it dies back in winter and then reinfests from seeds each spring (Pieterse et al., 1981). This habit could permit populations to persist in states with cold temperate climates. Populations have been recorded from as far north as the Erie Canal in upstate New York and Lake Erie in northern Ohio (Mike Weimer, US Fish and Wildlife Service, Buffalo, New York, and Doug Wilcox, US Geological Survey, Great Lakes Science Center, Ann Arbor, Michigan, pers. comm.).

Subtropical Florida harbors the most abundant waterlettuce populations in the eastern United States (Fig. 3). Other principal infestations occur in the warm temperate regions of the Gulf Coast states (Godfrey and Wooten, 1979), with the exception of Alabama (Kartesz, 1999). Scattered ephemeral populations – those that occur outside the naturalized range of waterlettuce and are of relatively recent origin, but which have been present for several years – have been recorded from Virginia, North Carolina, South Carolina, Mississippi, and northern Louisiana (USGS 2001). Some of these populations may persist over winter in the form of seeds, but others are likely being re-introduced each year. A few occasionally achieve nuisance proportions. Waterlettuce also occurs in California, Arizona, Puerto Rico, the Virgin Islands, and Hawaii (Degener, 1938; Kartesz, 1999;
USGS, 2001), but we have been unable to confirm reports (Kartesz, 1999) of isolated occurrences in Georgia, Maryland, and New Jersey.

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Waterlettuce is a perennial herb in the aroid family (Araceae). The plant consists of free-floating rosettes of many leaves. The rosettes occur singly or connected by short stolons. Leaves are gray-green, densely pubescent, and wedge shaped (obovate-cuneate). They have conspicuous parallel veins, frequently have thick spongy parenchymous tissue at the base, and vary from being slightly broader (at apex) than long to much longer than broad. Leaves range from 2 to 35 cm long. Roots are numerous and feathery. The inflorescences are inconspicuous pale-green spathes near the center of the rosette. Each spathe is constricted near the middle, with a whorl of male flowers above and a single female flower below the constriction. Fruits are many-seeded green berries, and the mature seed coat is thick, golden-brown, and wrinkled.

_Pistia_ is a monotypic genus in the subfamily Aroideae (Grayum, 1990). There are at least two extinct species: _Pistia siberica_ Dorofeev (Dorofeev, 1955, 1958, 1963) and _Pistia corrugata_ Lesquereux (Stockey et al., 1997). The genus also is closely associated with the fossil genus _Limnobiophyllum_ Krassilov, through which it is related to the Lemnaceae (Kvacek, 1995; Stockey et al., 1997).

Biology

Waterlettuce inhabits lakes, ponds, canals, and slow-flowing streams. The rosettes are perennial along the Gulf Coast, but act as annuals in more temperate zones. Waterlettuce exhibits seasonal growth in Florida with high rosette densities during winter and spring, and low densities during late summer and early autumn (Dewald and Lounibos, 1990; Dray and Center, 1992). Conversely, leaf size, leaf density per
rosette, and total biomass increase during spring and summer then begin to decline during late autumn (Dewald and Lounibos, 1990; Dray and Center, 1992). Population expansion is primarily by vegetative propagation. Up to 15 secondary rosettes may be attached to a single primary plant, and up to four generations of rosettes may be interconnected by stolons (Dray and Center, 1992). Standing crops may reach 2,000 g/m² by the end of the growing season (Dray and Center, 1992). Flowering occurs year-round in southern Florida, but peaks during summer and early autumn (Dray and Center, 1992). Dray and Center (1989) reported a crop of 726 seeds/m² on the rosettes at one site. The hydrosol under that waterlettuce infestation held 4,196 seeds/m². Mature seeds in fruits had an 84% germination rate, as did seeds in the upper 15 cm of the hydrosoil (Dray and Center, 1992). Historically, waterlettuce has been known to form large floating islands, nearly blocking upper reaches of the St. Johns River (Stuckey and Les, 1984), but these are uncommon today. Sculthorpe (1967) attributes this to suppression of waterlettuce by waterhyacinth after the latter was introduced into Florida during the late 19th century (see also Stoddard, 1989). Competition experiments between the two species support this conclusion (Tagel Seed, 1978; Agami and Reddy, 1990).

Analysis of Related Native Plants in the Eastern United States

Recent molecular phylogenetic analyses have unified the Lemnaceae within the Araceae, and shifted the aroids into the order Alismatales (Bremer et al., 1999; Chase et al., 2000). The resulting family contains more than 2500 species in about 150 genera (Zomlefer, 1994) and is distributed primarily throughout the tropics. Kartesz (1999) lists 40 native aroid species in 16 genera for the United States, many (12 species in six genera) of which are limited to Puerto Rico and the Virgin Islands. Nine of the remaining genera, containing a total of 26 species, occur in the eastern continental United States (USDA, 1999). Among these, *Pistia* forms a monophyletic group with the duckweed (Lemnaceae) genera (Stockey et al., 1997), all of which have species native to the eastern United States (*Spirodela*, two species; *Lemma*, nine species; *Wolffia*, four species; *Wolfiiella*, three species) (USDA, 1999). *Pistia*’s next closest affinities are with *Arisaema* (three species), which, like waterlettuce, belongs to the subfamily Aroideae (Grayum, 1990). Lasioideae is the subfamily most closely allied with the Aroideae, and it contains two genera with native representatives in the east: *Orontium* and *Sympercarpus* (one species each) (Grayum, 1990; USDA, 1999). The other aroid subfamily with native genera is the Calloideae, which is represented by *Calla* (one species) and *Peltandra* (two species). An examination of the conservation status of the Araceae shows that half of the 26 species in the eastern United States are considered imperiled in at least one state where *Pistia* occurs: *Spirodelapolyrhiza* (L.) Schleiden, *Wolffia brasiliensis* Weddell, *Wolffia braziliensis* Weddell, *Wolffia palustris* L., and *Wolffia umbellata* L. (Michx.) Morong. (ABI, 2000). The latter five species do not occur in the same habitat as *Pistia*, however.

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Area of Origin of Weed

Grayum (1990) suggested that *Pistia* is an ancient genus with subtropical Laurasian origins, which then migrated into tropical West Gondwanaland. This view is supported by recoveries of fossil *Pistia* species in strata from the Upper Cretaceous Period (103 to 65 million years ago [MYA]) in the United States (Wyoming and North Carolina) and southern France, and in strata from the Tertiary Period (65 to 2.5 MYA) in the southern United States and western Siberia (Stoddard, 1989). The colder climates associated with the Pleistocene Epoch (2.5 to 0.01 MYA) undoubtedly forced a sharp contraction of the genus’ distribution worldwide. Stoddard (1989) argues that Florida served as a refugium for *Pistia* during this period, and that the genus is therefore native to the United States. However, July temperatures in the southeastern United States averaged 12°C lower during the Pleistocene than today (Watts, 1980) and winters were almost certainly punctuated by severe freezes, so it is likely that the genus became extinct in the United States (Stuckey and Les, 1984). Support for this hypothesis is found in the paucity of specialist herbivores found on waterlettuce in Florida.
as compared to other regions of the world (Dray et al., 1993). For example, South America hosts at least thirteen specialist phytophagous insects (Dray et al., 1993) and at least two mosquitoes that are ovipositional specialists (Lounibos et al., 1992), which suggests a lengthy tenure on that continent (Bennett, 1975). Also, ancient folk medicines using Pistia are known from Africa and Asia (Stoddard, 1989), arguing for their antiquity in these regions. The extent of P. stratiotes’ distribution in Florida by the mid-18th century suggests that re-introduction into the United States occurred soon after European settlements were established (Stuckey and Les, 1984).

Areas Surveyed for Natural Enemies

Few surveys for natural enemies have specifically targeted P. stratiotes, aside from searches in Florida (Dray et al., 1988, 1993). However, several general aquatic plant surveys in India (Rao, 1964, 1970; Sankaran and Rao, 1974), Indonesia (Mangoendihardjo and Nasroh, 1976; Mangoendihardjo and Soerjani, 1978; Mangoendihardjo et al., 1979), and Thailand (Napompeth, 1990) noted the occurrence of herbivores on waterlettuce. Similarly, biological control scientists conducting surveys on Salvina spp. and waterhyacinth in South and Central America recorded natural enemies of waterlettuce (Bennett, 1975; DeLoach et al., 1976, 1979; Cordo et al., 1978, 1981; Cordo and DeLoach, 1982). Further, ecological studies of the Argentine waterlettuce fauna produced a few observations on herbivorous species (Poi de Neiff and Neiff, 1977; Poi de Neiff, 1983). Natural enemies have seldom been reported from Africa despite the presence of waterlettuce there for several millennia (Stoddard, 1989).

Natural Enemies Found

Dray et al. (1993) and Center (1994) discuss the herbivorous entomofauna reported from P. stratiotes worldwide. Among the species known or suspected to be plant-feeders, 44 include waterlettuce in their diets at least occasionally. The Neotropics harbor 21 waterlettuce-feeding insects, including at least 14 species of weevils – many of which are known only from this plant. Five waterlettuce herbivores have been reported from Africa, including a weevil (Bagous pistiae Marshall) known exclusively from P. stratiotes. The African fauna also contains a collembolan known exclusively from waterlettuce, but it is unclear whether this insect is a herbivore. Eleven phytophagous insects, including eight moth species (one of which is a specialist – Spodoptera pectinicornis [Hampson]), have been observed feeding on waterlettuce in Asia. Nine insects feed on waterlettuce in Florida, including a moth (Argyracis [=Petrophila] drumalis [Dyar]) whose larvae only have been found on waterlettuce roots (Dray et al., 1989; Dray et al., 1993; Habeck and Solis, 1994).

Host Range Tests and Results

Host range trials have been conducted on several of the Neotropical weevil species, a Neotropical grasshopper, and two moth species (one Asian and one Neotropical). DeLoach et al. (1976), Harley et al. (1984), and Thompson and Habeck (1989) studied the host range of the weevil Neohydronomus affinis Hustache (as N. pulchellus Hustache), testing a total of 89 species in 66 genera and 37 families. Aside from waterlettuce, only duckweed (Spirodela and Lemna) and frogbit (Limnobium) species sustained any oviposition or meaningful feeding. As noted above, the duckweeds and Pistia group together in a single clade within the Araceae, and Limnobium has spongy tissues similar to Pistia (Thompson and Habeck, 1989) as well as being in a family (Limnocharitaceae) closely related to the aroids (Chase et al., 1995). Cordo et al. (1978) reported that adults of the weevil Argeninorhynchus bruchi (Hustache) fed and oviposited, and larvae completed development, only on waterlettuce (with very slight feeding on Spirodela intermedia W. D. J. Koch) among the 31 plant species (21 genera, 12 families) they tested. Host range trials conducted by Cordo et al. (1981) demonstrated that the weevil Pisticola (as Onychylis) cretatus (Champion) has a diet similar to N. affinis. These authors also reported that the weevil Ochetina bruchi Hustache has a broad food-host range, but failed to identify its developmental host.

Larvae of the pyralid moth Samea multiplicalis (Guenée) fed on eight of 17 species (15 genera, 11 families) included in two separate host range studies, but adults oviposited almost exclusively on waterlettuce (Knopf and Habeck, 1976; DeLoach et al., 1979). Food hosts are summarized by Center (1994). The noctuid moth S. pectinicornis (= Proxenus hennia, variously placed in the genera Xanthopter, Athetis, Namangana, and Episamia) was tested against a total of 125 plant species (in 103 genera and 49 families), but completed development only on
waterlettuce (Mangoendihardjo and Nasroh, 1976; Suasa-Ard, 1976; Habeck and Thompson, 1994). Feeding and oviposition also were largely confined to this plant. The acridid grasshopper *Paulinia acuminata* (De Geer) feeds and develops on the waterferns (*Salvinia* spp. and *Azolla* sp.) as well as waterlettuce (Bennett, 1966; Vieira, 1989).

**Releases Made**

Only two insects have been released into the United States as biological control agents against this weed, the South American weevil *N. affinis* and the Asian moth *S. pectinicornis* (Dray *et al.*, 1990, 2001).

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**BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES**

*Neohydronomus affinis* Hustache (Coleoptera: Curculionidae)

Adult *N. affinis* (Fig. 4a) weevils are small (3 mm long) and have a nearly straight rostrum that is strongly constricted ventrally at the base. *Neohydronomus affinis* ranges in color from uniform bluish gray to reddish brown with a tan, chevron-like band across the elytra. Further information on the identification of this species may be found in DeLoach *et al.* (1976) or O’Brien and Wibmer (1989). The following summary of this weevil’s biology is based on DeLoach *et al.* (1976) and Thompson and Habeck (1989).

Eggs are cream colored and subspherical (0.33 x 0.4 mm). Females chew a hole about 0.5 mm diameter in the leaf (usually on the upper surface near the leaf edge), deposit a single egg inside this puncture, and close the hole with a black substance. Eggs hatch within four days (at temperatures above 24°C). Young larvae (Fig. 4b), which are very small (head diameter of 0.2 mm), burrow under the epidermis and work their way toward the spongy portions of the leaf at a rate of about 1.5 to 2.0 cm/day.

Larval mines (Fig. 4c) often are visible in the outer third of the leaf where tissues are thin, but are less apparent in the central and basal portions of the leaf. The first molt occurs when larvae are about three days old, the second molt occurs 3 to 4 days later. The three larval stages last 11 to 14 days in total.

**Figure 4a.**

**Figure 4b.**

**Figure 4c.**

**Figure 4.** Adult (a) and larvae (left) and pupa (right) (b) of the waterlettuce weevil *Neohydronomus affinis* Hustache. Mining by larvae produces characteristic tunnels (c). (Photograph courtesy of USDA, ARS Invasive Plant Research Laboratory.)
Third instars are generally found excavating the spongy portions of the leaf where they pupate. Under optimal temperatures, 4 to 6 weeks are required for *N. affinis* to develop from egg to adult. Adults chew holes (about 1.4 mm in diameter) in the leaf surface and burrow in the spongy tissues of the leaf. The characteristic round feeding holes are easily observed when weevil populations are large (several hundred insects per m²), but may be concentrated near leaf edges and more difficult to observe when populations are small.

*Samea multiplicalis* (Guenée) (Lepidoptera: Pyralidae)

The following section summarizes the biology of the pyralid moth *S. multiplicalis* based on observations of several authors (Knopf and Habeck, 1976; Deloach et al., 1979; Center et al., 1982; Sands and Kassulke, 1984). Adults are small (wingspread about 17 mm), tan moths with dark markings on fore and hind wings (Fig. 5a). Females each lay about 150 eggs during their brief life span (four to seven days). Eggs most often are laid singly among the epidermal host plant hairs on the lower surfaces of waterlettuce leaves or the upper surface of *Salvinia* leaves, or lodged between the scale-like leaves of *Azolla*. Eggs hatch in about four days (at 28°C). Larvae (Fig. 5b) may feed from within a refugium made of silk and hairs of the host plant attached to the external leaf surface, or within galleries in the leaves (waterlettuce). The refugium, when present, consists of a silk canopy stretched across the surface of the leaf. Larvae periodically extend the area covered to reach fresh leaf material. Larger larvae feed on the buds of plants, often killing the growing apex. Larvae also will eat mature waterlettuce fruits and consequently destroy the enclosed seeds. The larval stage is composed of five to seven instars, which require 15 to 16 days for development at 28°C when fed waterlettuce or *S. minima* and 21 to 35 days at 26°C when fed *S. molesta*.

Pupation occurs within a silken cocoon. On waterlettuce, this cocoon usually is formed within the spongy portion of a leaf, but on *S. molesta* it is constructed among old leaves. Pupal development requires four to seven days at 28°C on waterlettuce and eight to nine days at 26°C on *S. molesta*. The total developmental times (egg to adult) are 25 and 42 days under the two respective temperature/host plant regimens.

Populations of *S. multipticalis* tend to be sporadic, possibly due to high parasitism rates. Nonetheless, densities can become exceedingly high during intervals of peak abundance. If this coincides with cooler periods and correspondingly slow waterlettuce growth, massive destruction of the mat results. Nonetheless, because of lack of persistence by this species, the waterlettuce mats normally recover later during the growing season.

*Spodoptera pectinicornis* (Hampson) (Lepidoptera: Noctuidae)

Several authors have reported on the noctuid moth *S. pectinicornis* (Fig. 6a) (George, 1963; Suasa-Ard, 1976; Mangoendihardjo and Soerjani, 1978; Suasa-Ard and Napompeth, 1982; Habeck and Thompson 1994). The following section summarizes their observations. Female *S. pectinicornis* oviposit on both surfaces of waterlettuce leaves. Eggs are laid in masses...
(Fig. 6b) of up to 150 eggs each (average 94 eggs per mass) and covered by a substance produced by the female, perhaps scales from her abdomen. Oviposition lasts two to six days and each female lays up to 990 eggs (average 666 eggs per female). The incubation period ranges from three to six days (average 4.4 days). Eggs are subspherical, about 0.03 mm in diameter, greenish when newly deposited, and turn yellow as they develop.

First instars are creamy white and feed within the leaf on the spongy tissues. Larval development progresses through seven instars and requires 17 to 20 days (average 18 days). Fully-grown larvae attain lengths of up to 25 mm. They pupate in a leaf base or between the leaves, or between the thick ribs on the underside of the leaf. The pre-pupal period lasts one to two days and the pupal stage lasts 3.5 to 5.5 days. Total generation time is about 30 days.

Caterpillar feeding causes plant destruction. Although considerable damage accrues on leaves (Fig. 6c), this alone probably would not kill plants. However, larvae also destroy meristematic tissue, which prevents leaf replacement and impedes asexual reproduction. George (1963) estimated that one hundred caterpillars from one average-sized egg mass could destroy the waterlettuce within a 1 m² area. He also calculated that a single caterpillar, during its larval development, eats two sizable waterlettuce rosettes at a rate of one leaf per day.

In India, periods of peak *S. pectinicornis* occurrence coincide with monsoons and with periods of rapid waterlettuce growth. During these periods, moth infestations occur at most sites and the destruction to waterlettuce mats frequently exceeds 75%. During dry periods, fewer sites are infested and smaller proportions of the waterlettuce populations are affected. However, moth populations are reportedly present all year and produce continuous, overlapping generations.

**Synclita obliteralis** (Walker) (Lepidoptera: Pyralidae)

The following information is derived from Lange (1956), Kinser and Neunzig (1981), and Habeck (1991). Adults (Fig. 7a) are small moths; males are distinctly smaller (wingspread 11 to 13 mm) than the females (wingspread 15 to 19 mm). The wings of males are dark in coloration, but interspersed with brown and white markings. The wings of females

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**Figure 6.** Adult (a) and egg mass (b) of the waterlettuce moth *Spodoptera pectinicornis* (Hampson). Damage from larval feeding (c) can destroy leaves. (Photograph courtesy of USDA, ARS Invasive Plant Research Laboratory.)
are paler grayish brown with orange and dark markings.

The whitish eggs are oval and flattened, appearing domelike. They are laid near edges of submersed leaf-surfaces of aquatic plants and are placed singly or slightly overlapping, often in ribbon like masses. Larvae (Fig. 7b) reside between two roundish pieces of leaves that form a sandwich-like portable case. When feeding on small plants, these cases can consist of whole leaves or even whole plants. Cases are usually, though not exclusively, constructed from the plant species on which the larva is feeding. The cases made by young larvae are waterfilled, and these larvae obtain oxygen through their skin. Cases of older larvae are airfilled. Larvae extend the anterior portion of their bodies out of the case to feed on surrounding plants. They abandon smaller cases as they grow larger, and then cut pieces from new leaves to construct larger cases.

Unlike most nymphulines, larvae of \textit{S. obliteralis} lack tracheal gills. The general body color is creamy white grading into brownish anteriorly (towards the segments that protrude from the case). The epidermal surface is textured with minute papillae that create a distinctive satiny appearance. The head is yellowish or brownish with patches of slightly darker coloration. Before pupation, larvae attach their cases to leaves of aquatic plants either above or below the water surface. They then spin cocoons within the cases in which to pupate.

**EVALUATION OF PROJECT OUTCOMES**

**Establishment and Spread of Agents**

Dray \textit{et al.} (1990) describe the release and establishment of the weevil \textit{N. affinis}, which was initially released at seven sites in southern Florida in 1987 and 1988. Populations established at four of these sites within a year. By fall of 1990, the weevils had dispersed to waterlettuce-infested canals and ponds up to 25 km from initial release sites on Lake Okeechobee (Dray and Center, 1992). Collaborators with the South Florida Water Management District and the Florida Department of Environmental Protection collected infested waterlettuce plants and transplanted them into about 30 additional waterways throughout the state in the spring of 1989 (Dray and Center, 1992). The weevil also was recovered from several sites in southern Louisiana during surveys in spring and summer 1990, although how it arrived there remains unclear (Grodowitz \textit{et al.}, 1992). Surveys during the fall of 1991 showed \textit{N. affinis} populations had become established at 45 sites in Florida and six sites in Louisiana (Dray and Center, 1993). The weevil also was released at one site in Texas in the fall of 1991 (Grodowitz \textit{et al.}, 1992).

The moth \textit{S. pecitnicornis} was released at 22 sites in southern Florida from 1990 to 1997 (Dray \textit{et al.}, 2001). Several provisionally established populations developed, but ultimately failed to persist (Dray \textit{et al.}, 2001).
Suppression of Target Weed

*Neohydronomus affinis* has produced dramatic declines (up to 90%) in waterlettuce abundance at five sites in Florida (Fig. 8) and two in Louisiana (Dray and Center, 1992, 1993). Long-term suppression of this weed has not occurred, however, although in at least one site in Florida there were annual cycles from 1990 to 1994 in which spring increases in waterlettuce abundance were followed by sharp declines attributable to the weevil (Dray, unpub.). Plants under stress from weevil feeding are typically smaller, have fewer leaves, and grow less rapidly than un-infested plants (Dray and Center, 1992).

Recovery of Native Plant Communities

There have been no studies investigating the re-emergence of native plant communities at sites where waterlettuce control has occurred.

Economic Benefits

There are no known economic benefits accruing from this project.

RECOMMENDATIONS FOR FUTURE WORK

Future Needs for Importation or Evaluation

Although the weevil *N. affinis* has been used successfully in other countries, it has had only limited effect in Florida (Dray and Center 1992). Furthermore, the moth *S. pectinicornis* has failed to establish (Dray et al. 2001). Hence, new biocontrol agents are needed. Many additional natural enemies are known from South America that should be studied further to assess their value. Waterlettuce has never been thoroughly surveyed for natural enemies, having generally been a side project of research focused on waterhyacinth or *Salvinia molesta*. Hence, it is anticipated that intensive faunal surveys would reveal many more potential biological control agents.

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