LABORATORY EVALUATION OF THE BLADDERWORT PLANT, *UTRICULARIA VULGARIS* (LENTIBULARIACEAE), AS A PREDATOR OF LATE INSTAR *CULEX PIPIENS* AND ASSESSMENT OF ITS BIOCONTROL POTENTIAL

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Bladderworts are temperate/tropical carnivorous plants with both aquatic and terrestrial species. The aquatics are often rootless and occur as free-floating mats in quiet, acid ponds and bogs. From their branching stems arise whorls of smaller branches that bear numerous, small (0.3–5 mm) traps or bladders (Fig. 1), said to be the most sophisticated among carnivorous plants (Lloyd 1942, Slack 1980).

Protozoans, rotifers, water fleas, and other small crustaceans are common prey of *Utricularia* (Skutch 1928, Lloyd 1942). Mosquito larvae, particularly early instars, have also been observed in *Utricularia* traps and several investigators have proposed their usefulness in mosquito control (Matheson 1930). Within the confines of jars and artificial pools several *Utricularia* species exhibit high predation rates (60–100%) on mosquito larvae (Skutch 1928, Matheson 1930, Twinn 1931, Lloyd 1942, Angerilli and Beirne 1974), and in field studies several *Culex* and *Anopheles* species have been repeatedly observed within *Utricularia* traps (Twinn 1931, Evans and Garnham 1936). Their potential as a mosquito control agent is great considering that a 220 cm branch from *Utricularia neglecta* Lehmann supports 13,860 bladders, of which 83% contained organisms on examination (Skutch 1928). However, Curry (1934) reported that *Utricularia mixta* Barnh. trap few *Anopheles* larvae due to its minute traps and may foster larval development by providing a substrate for larval food. Little information is available on the potential or actual predation on mosquitoes by one of the most common, widespread, and biologically understood species, *Utricularia vulgaris* Linn. *Utricularia vulgaris* is particularly attractive as a biocontrol agent because of its circumboreal distribution, ability to grow in shallow (<60 cm), neutral waters (Slack 1980), tolerance of drought, and its overwintering capacity (Winston and Gorham 1979). This study was undertaken to: determine the prevalence and natural habitat of *U. vulgaris*; evaluate its predation on *Culex pipiens* Linn. in outdoor tanks; and to access its usefulness in the biocontrol of mosquitoes and integration into the operations of a mosquito abatement district in Illinois.

In June, July and August 1986 at least 5 permanent and/or temporary (floodwater) stagnant water sites (i.e., ditches, marshes, field or woodland flood areas) scattered throughout a 310 km^2 suburban/rural area in northwestern Cook County, northeastern Illinois were inspected daily for the presence of bladderworts. The surveyed sites, all flooded at the time of inspection, were randomly chosen from detailed maps of all potential mosquito breeding sources within the jurisdiction of the Northwest Mosquito Abatement District. A minimum of 2 widely separated, near-shore points at each water source were carefully searched for floating bladderworts and data recorded as to the presence or absence of these plants, site location, and water permanence (determined by past 10 year history records) at each site. The possibility exists that some plants may have been overlooked because of their patchy distribution within a site. When sites positive for bladderworts were discovered, additional data such as the water pH (wide range test paper), plant density (length of plants per area), water depth below plants, plant distance from shore, degree of shading by cattails, associated aquatic plants, and presence of mosquito larvae were also accumulated. Plant and mosquito samples from every positive site were retrieved for identification. All bladderworts were identified as *U. vulgaris*. Voucher plant material has been deposited at the Morton Arboretum and Chicago Field Museum. No concerted effort was made to survey deep-water, ornamental and retention ponds and lakes since *U. vulgaris* is strictly a shallow-water plant (Swink and Wilhelm 1979).

Only 5 of 358 (100 permanent and 258 temporary water) sites (size 6.0–10,800 m^2) inspected were positive for bladderworts. The fact that all 5 bladderwort sites were previously categorized as permanently wet and the absence of bladderworts in numerous roadside ditches (not included in total) suggest that temporary floodwater sites are unsuitable for plant growth. The wide separation (2–10 km) of bladderwort sites, with marshes positive and negative for plants in close proximity (10 m), and the uneven distribution of plant mats over entire sites (patchy along margins) also imply poor plant

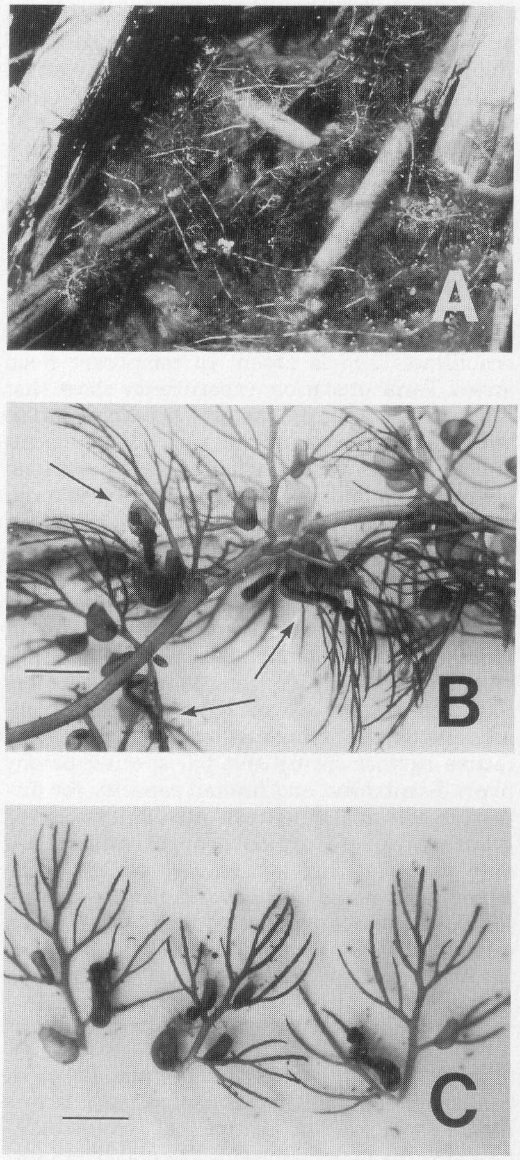

Fig. 1. A) Bladderwort plants, *Utricularia vulgaris*, and lesser duckweed, *Lemna minor* Linn., in situ at base of cattails; B) Enlargement of plant showing *Ae. vexans* larvae entrapped by bladders and; C) Excised leaves with engulfed larvae. Scale bar = 5 mm.

dispersal and colonization of new areas. Bladderworts were found in both open, sunny water areas and in shaded water among dense cattails (Fig. 1A), but the greatest plant density and mat extension occurred in open areas. Plants floated near shore out to 3 m (early summer) or 7.6 m (late summer) distance in water depths from 7.6 to 61 cm ($\bar{x}$ = 27.4 cm, n = 12). Mean density of plants was 238 cm length of floating stem (range 15–732 cm, n = 14) in 929 cm^2 area. Water at bladderwort sites was equal in acidity to sites without plants (pH 6, n = 20), which agrees with statements that the plant has no acidity requirements unlike other *Utricularia* species (Slack 1980).

Continued surveillance of bladderworts throughout the summer revealed that the plants exposed to full sun flowered through June with continued dense and expansive mat growth through July. By mid-August plant overgrowth and eutrophication occurred at many sites; plants browned, leaves dropped off, and bladders blackened and abscised with the advance of cool weather. Winter bud (turion) formation accelerated as usually occurs under unfavorable growing conditions (Winston and Gorham 1979) and many plants had sunk to the marsh bottom by early October. These phenological changes agree with general reports on the ecology of the species elsewhere in response to temperature and day length fluctuations (Winston and Gorham 1979, Slack 1980).

Live mosquito larvae of mixed instars were occasionally observed among bladderworts in situ. A heavy hatch of *Aedes vexans* (Meigen) was encountered among low density plants, following recent flooding of a permanent marsh in July. *Culex territans* Walker frequently occurred at a low density (1/3 dips) among loose mats at 3 sites and on September 11 a few *Cx. territans*, *Culiseta inornata* (Williston), *Anopheles punctipennis* (Say), and *Uranotanea sapphrinia* (Osten-Sacken) were recovered from another mat. A 7-year breeding history of the bladderwort sites showed that all have sampled positive for mosquito larvae 11–31% of the time. Earlier observers have also noted the presence of mosquitoes thriving among bladderworts (Twinn 1931, Evans and Garnham 1936).

The predatory nature of *U. vulgaris* on *Cx. pipiens* was evaluated in outdoor tank tests by combining field-collected plants with late instar larvae and tallying the remaining live immature mosquitoes. In each experiment, plants were carefully removed, minimizing handling, from a different field site and transported in buckets of water to the experimental glass aquaria (25 × 48 cm, ca. 15 cm deep water) within 2 hr, where ca. 460 cm of plant stems were evenly distributed over the water surface of each tank and allowed to remain undisturbed for 2 days to permit resetting of any triggered traps. Angerilli and Beirne (1982) have implied that stressed *Utricularia minor* Linn. shed their bladders on transportation but this has not been reported previously for *U. vulgaris* and such was not observed here. Traps triggered without capturing prey, as may occur during transportation, usually recover within 15 min to 2 hr depending on the species (Skutch 1928, Lloyd 1942). The test plant density herein chosen was previously determined to be comparable to that found in nature at some sites. Tank water consisted of unprocessed well water which was changed between successive experimental trials. Field collected mosquito larvae (60 third or fourth instars) were then introduced within 4 hr into the center of each tank, with all larvae per trial of the same developmental instar from the same source (culverts or marshes). Tanks with equal number of mosquito larvae but without plants served as controls. Liver powder (1.7 g) was added as larval food to fresh tanks and subsequently every other day throughout the experiments; failure to provide this in the first 3 trials resulted in high larval mortality among both tests and controls due to starvation. The top of each tank was covered throughout as a shield from rain and the heat of sunlight, and again, disturbances were kept to a minimum so as not to cause shadowing, excessive larval repelling, and increased captures due to human intervention. At the termination of each experiment, 3 days of plant-mosquito contact, all remaining live larvae were tallied. Prior to each larval count (3 repeat counts/tank) after predation, plants were slowly and carefully removed from aquaria so as not to obscure floating larvae. False counts due to eclosion of mosquitoes were considered negligible since this would also apply to controls, and pupal skins were rarely detected. Two control and 3 test trial replicates were run for each of 8 experiments during the summer. The number of bladder traps per stem length over various stem sizes and ages [$\bar{x} = 240$ traps/30.5 cm stem, n = 40; only 80 of these large enough (≥ 3 mm diam) to capture 4th instar larvae] extended to the amount of plant material in the tanks, provided a rough estimate of the average number of large traps introduced per experimental tank (1,200).

Predation experiments revealed that bladderworts at a density comparable to field conditions have a substantial effect on the survivorship of *Cx. pipiens* in confined tanks lacking other competitive prey organisms. Significantly ($P < 0.01$, $t = 12.235$, df = 13) more larvae survived in the controls ($\bar{x} = 55.6 \pm 3.8$, range 41–60) than tests ($\bar{x} = 27.1 \pm 5.4$, range 14–43) after 3 days exposure to 460 cm of plant stem (1,200 large potentially active bladder traps) among all 8 experiments. In similar tank experiments, *U. minor* stems possessing 200–300 bladders consumed all of 100 first or third instar *Aedes aegypti* (Linn.) within a week (Angerilli and Beirne 1974). Although not every trap herein was inspected for captured larvae, many entrapped larvae were observed. Because of size discrepancies between bladders and larvae, only the anterior or posterior half of 4th instars were initially sucked into traps (Figs. 1B and 1C), probably resulting in larval death by suffocation (Skutch 1928), and the entire larva was subsequently ingested within 3 days as has been reported for other bladderwort species (Evans and Garnham 1936, Lloyd 1942). Pupae were never observed within bladders in tank tests or in the confines of jars packed with plants and immature mosquitoes (agitated every 2 hr in 12 hr). The enlarged, spherical shape of pupae probably resisted ingestion by the smaller bladders.

In summary, *U. vulgaris* naturally inhabits only 5% of permanent water marshes in northern Illinois and is absent in temporary flood areas. Tank predation experiments show that ca. 50% of 60 fourth instar *Cx. pipiens* larvae are killed by plants in 3 days at a density comparable to that in nature. These results and field observations imply that *U. vulgaris* takes a toll on mosquito larvae under natural conditions but falls short as an efficient biocontrol agent in applied mosquito abatement because of: competing natural prey; only moderate larval mortality at mat densities as in nature; evidence of mosquito survival among mats in situ; reliance on prey to contact bladders; failure of bladders to trap pupae; slow plant growth in early summer and rapid die-back at summer's end, ineffective against spring and fall species; patchy plant distribution and limited capacity for dispersion within and between sites; and restricted growth sites—plant growth apparently limited only to permanent water sites, useful in the reduction of some *Culex* spp. but inappropriate for floodwater mosquitoes (*Aedes* spp.) which constitute 87% (7 yr average at light traps) of the major pests in Illinois.

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