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Communities of Larval and Juvenile Fish Associated with Water-chestnut, Watermilfoil and Water-celery in the Tivoli Bays of the Hudson River

A Report to the Hudson River Foundation

by Robert E. Schmidt and Erik Kiviat

Hudsonia Ltd.
Bard College Field Station, Annandale NY 12504 USA

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Abstract

Water-chestnut (*Trapa natans*) is a rooted, floating aquatic vascular plant introduced to the northeastern United States from Europe a century ago. Dense growth of water-chestnut crowds out submerged macrophytes and, along with its spiny nuts, is a nuisance and hazard to boaters, fishers, and bathers. In separate beds of water-chestnut, water-celery (*Vallisneria americana*) and Eurasian watermilfoil (*Myriophyllum spicatum*), we sampled phytomass (0.25 m^2 aboveground plots, every 2 weeks) and larval and juvenile fishes (light trap and dip net, weekly) mid-June to mid-September 1987 in the freshwater-tidal Tivoli Bays of the Hudson River, New York. Water-chestnut mass was consistently more than twice that of water-celery or watermilfoil, with peak water-chestnut dry weight 400-500 g/m^2. We caught more fish species and more individuals in water-chestnut beds; 81 individuals of 9 species in water-chestnut, 22 individuals of 5 species in water-celery, and 13 individuals of 6 species in watermilfoil. The very low catch-per-effort (maximum 1 fish per 10 light trap minutes) may have been due to high turbidity. The most abundant species in water-chestnut were banded killifish (*Fundulus diaphanus*) and common carp (*Cyprinus carpio*). Water-chestnut, perhaps because of its density and abundant associated small animals, seems excellent habitat for small fish.

1 Introduction

Fresh-tidal marshes and associated subtidal shallows have been the subject of intensive ecological research only since the early 1970s (Odum et al. 1984). Results have shown the marshes to have high primary productivity, yet support floristically, spatially, and temporally diverse communities of vascular vegetation. With the exception of studies in the Chesapeake Bay region (e.g., Southwick and Pine 1975, Bayley et al. 1978, Stevenson and Confer 1978, Orth and Moore 1984), little work has been done on the ecology of freshwater subtidal vascular vegetation, and apparently no research has been done on floating-leaved species.

Many introduced species have been studied because of economic and conservation concerns, and among these are many aquatic plants (Mitchell 1974). Introduced nuisance plants generally replace other plants of different growth form. It is well known that plants with large masses of floating material can out-compete submerged species. Introduced species offer models for investigation of ecological processes at the population, community, ecosystem, and evolutionary levels as illustrated by Bates (1956) and Elton (1958). The invasion of water-chestnut offers an opportunity to learn about the relationship of structure to function in fresh-tidal shallows vegetation, as well as adding to the scant general knowledge of these communities. We know of no broad study of an introduced floating-leaved species in temperate North America, no comparison of the ecology of submerged plants with floating-leaved plants on the mid-Atlantic Coast of the United States, no quantitative ecological study of water-chestnut in North America, and no quantitative study of water-chestnut in tidal waters anywhere.

Limited information on the life history, distribution and spread of water-chestnut in the Hudson and other waters of the Northeast has appeared in print (Anon. nd, Davenport 1879, Muenscher 1935, Eaton 1947, Smith 1955, Rawls 1964, Wich 1968, Countryman 1970, 1978a, b, Burk et al. 1976, Kiviat 1978, Besha and Countryman 1980, Hall 1982). Experiments on control or utilization of water-chestnut were reported by Smith (1955), Besha and Countryman (1980), Hall (1982), and others. *Trapa natans* and its close congener or conspecific *T. bispinosa* have been studied to some extent in nontidal waters in Eurasia. In northern Europe, water-chestnut is rare and declining (e.g., Shilov 1980). In some regions of India cultivated water-chestnut nuts are eaten and the plant is an important protein crop (Khatib 1934, Purohit and Vakil 1984). Production, nutrient exchange, and decomposition of water-chestnut have been studied in Japan (Tsuchiya and Iwaki 1979-84, Matsuo et al. 1979). Kiviat (1987) reviewed the ecology of water-chestnut as a pest in New York.

Water-chestnut (*Trapa natans*), also known as water-caltrop, water-nut, Jesuit's nut, Singhara nut and bull nut is a large aquatic vascular plant in the family Trapaceae (Hydrocaryaceae). Native to Eurasia, it is not related to the cultivated Chinese water-chestnut, *Eleocharis dulcis* (*E. tuberosa*), a spike-rush of the family Cyperaceae (Herklots 1972).

Water-chestnut in the Northeast is an annual with germination and rapid development of stems and rosettes in late spring, maximum water surface coverage from late June through early September, and rapid senescence and decomposition in September and October. An individual water-chestnut plant comprises a nut husk which acts as an anchor in the mud, a long trailing stem bearing finely divided submerged leaves

and water roots, and several rosettes of somewhat succulent, floating, rhombic leaves with small whitish flowers between the inflated petioles. The mature rosettes are 30 cm or more in diameter and each one may produce 10-15 blackish 3 cm wide nuts, each nut bearing 4 large barbed spines. The mature nuts drop to the bottom; the seeds remain viable in the sediments over 1-5+ winters (Hook 1985).

Water-chestnut was introduced to a lake in Scotia, New York, a century ago whence it escaped into the Mohawk River (Smith 1955). By the time of the 1930s State Biological Surveys, water-chestnut was widespread in the tidal Hudson River and was already considered a pest (Muenscher 1935). Due to independent introductions and dispersal by people, equipment, animals and currents, water-chestnut appeared at a number of other locations in the Northeast and has caused concern in the Sudbury River (Massachusetts), the Potomac River, Lake Champlain, and smaller water bodies (Rawls 1964, Countryman 1970, 1978a,b). There were 4,000 hectares of water-chestnut in the Potomac in 1933 (Rawls 1964), although subsequently the species disappeared entirely from the Potomac, evidently due to control operations and possibly also because of deteriorated water quality (Orth and Moore 1984; Virginia Carter, U.S. Geological Survey, pers. comm. 1988). In the last few years, water-chestnut has begun to invade farm ponds, mill ponds, and sluggish stream reaches in the mid-Hudson Valley, New York (Kiviat and Schmidt, pers. observations).

Calm, shallow, circumneutral, nutrient-rich waters of the Northeast may become completely covered by dense masses of water-chestnut, with large numbers of the nuts and nut husks accumulating in the sediments and along the shoreline. Environmental impacts reported or suspected to result from dense water-chestnut infestations include (see, e.g., Martin et al. 1957): 1. Shading out native aquatic plants including rare species; 2. Out-competing waterfowl food plants (e.g., water-celery, pondweeds) (Martin and Uhler 1939); 3. Speeding sedimentation and vegetation development rates (Robert L. Bard, pers. comm.; 4. Producing a nuisance (the spiked nuts) to people and a possible hazard to wildlife; 5. Acting as a source of seeds to infest other water bodies; 6. Modifying water chemistry by shading during the growing season and by producing a large oxygen demand during rapid decomposition in early fall; 7. Affecting fish communities by altering subtidal habitat structure; 8. Intefering with boating, fishing and swimming; 9. Providing breeding habitat for mosquitos (Anonymous nd); 10. Creating abundant organic material that may be a precursor to toxic trihalogenated methanes in drinking water (Besha and Countryman 1980); and 11. Entangling larger animals (Connor 1978). (The last problem is probably very rare but the reported incident involved an osprey at Tivoli South Bay on the Hudson River.)

For about 15 years the New York State Department of Environmental Conservation controlled Hudson River water-chestnut with the herbicide 2,4-D and by hand-pulling (Wich 1968, Robert L. Bard pers. comms., William D. Countryman pers. comms.). The maximum application of 2,4-D now permitted in water bodies by Federal regulation (2 lb/acre acid equivalent) is ineffective against water-chestnut (Hall 1982). Since the water-chestnut control program was terminated (the last year of spraying was 1975), the plant has rapidly reattained dominance of most sheltered coves and shallows in the tidal Hudson as far south as Constitution Island (Putnam County), with scattered patches and individuals down to Iona Island (Rockland Co.) where it is limited by salinity.

Table 1. Common and scientific names of organisms mentioned in this report. Names follow Mitchell (1986) for plants and Robins et al. (1980) for fishes.

Plants	
Arrow arum	*Peltandra virginica*
Canadian waterweed	*Elodea canadensis*
Cattail	*Typha* sp.
Charophyte	Charophyta
Coontail	*Ceratophyllum demersum*
Duckweeds	Lemnaceae (a)
Eurasian watermilfoil	*Myriophyllum spicatum*
Horned pondweed	*Zannichellia palustris*
Naiad(s)	*Najas* sp(p).
Narrowleaf cattail	*Typha angustifolia*
Northern watermilfoil	*Myriophyllum exalbescens*
Nuttall's waterweed	*Elodea nuttallii*
Pickerelweed	*Pontederia cordata*
Pondweeds	*Potamogeton* spp.
Purple loosestrife	*Lythrum salicaria*
Redhead-grass	*Potamogeton perfoliatus*
Softstem(?) bulrush	*Scirpus ?tabernaemontanii*
Spatterdock	*Nuphar luteum*
Subulate arrowhead	*Sagittaria subulata*
Water-celery	*Vallisneria americana*
Water-chestnut	*Trapa natans*
Watermilfoil	*Myriophyllum spicatum*
Water stargrass	*Heteranthera dubia*
Willow	*Salix*
Fishes	
Alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
Banded killifish	*Fundulus diaphanus*
Common carp	*Cyprinus carpio*
Fourspine stickleback	*Apeltes quadracus*
Golden shiner	*Notemigonus crysoleucas*
Goldfish	*Carassius auratus*
Inland silverside	*Menidia beryllina*
Redbreast sunfish	*Lepomis auritus*
Silvery minnow	*Hybognathus regius*
Spottail shiner	*Notropis hudsonius*
Tessellated darter	*Etheostoma olmstedi*
Unidentified herring	*Alosa* sp.
White perch	*Morone americana*

a One or more of the following species: *Lemna minor, Spirodela polyrhiza, Wolffia* sp.

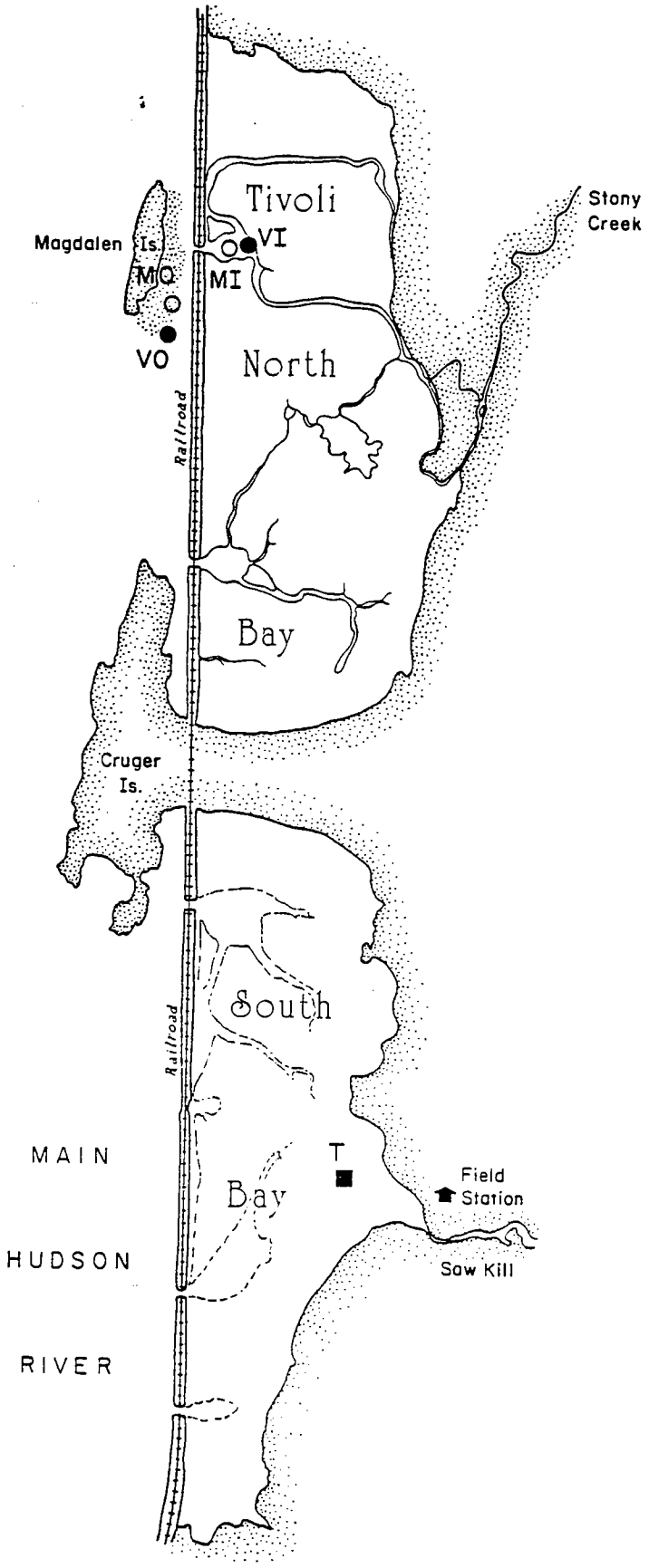
Species composition and biomass of native and introduced subtidal vascular plants in fresh-tidal and brackish tidal shallows can fluctuate drastically over periods of years or decades (Southwick and Pine 1975, Bayley et al. 1978, Stevenson and Confer 1978, Orth and Moore 1984). These fluctuations have major impacts on the physical structure of estuarine habitats and the functioning of food webs. Fisheries in

major estuaries of the East Coast are affected by a multitude of problems including toxic substance contamination, overharvest, and changes to habitats. The shallows and wetlands of the tidal Hudson River are important habitats for juvenile and adult fish of many species (Rod and Sramek 1986, R. E. Schmidt 1986, Kiviat unpubl. data). The increase in abundance of water-chestnut in the Hudson is probably the most important factor currently affecting subtidal vascular vegetation.

Many studies have shown that larval and juvenile fishes utilize vegetation in freshwater (Hall and Werner 1977), tidal freshwater (Rozas and Odum 1987) and marine (Orth et al. 1984) environments. By creating structurally complex habitats, submerged aquatic vegetation may provide food (Watkins et al. 1983) and/or hiding places from predators (Boesch and Turner 1984; Gotceitas and Colgan 1987) for small fishes. Fish abundance, therefore, can be substantially higher in aquatic vegetation than in contiguous areas without plants (Holland and Huston 1984; Rozas and Odum 1987). Because of the above observations, aquatic vegetation stands have been considered significant as nursery areas for estuarine fishes.

The invasion of water-chestnut in the Hudson River has certainly altered the composition of vegetation in the quiet shallows. A purpose of this study was to determine if water-chestnut was a nursery area for larval and juvenile fishes and if any differences could be detected between water-chestnut stands and other plant communities. We chose to compare water-chestnut stands with stands of water-celery and Eurasian watermilfoil because water-celery (native) and Eurasian watermilfoil (introduced species) are the other most abundant subtidal macrophytes in the fresh-tidal Hudson River, and they are the species that would probably dominate much of the area covered by water-chestnut if the water-chestnut could be removed.

Fig. 1. Tivoli Bays study area with sampling sites (MI and MO = watermilfoil sites; T = water-chestnut site; VI and VO = water-celery sites). Scale approximately 1:24,000.



2 Study Areas

2.1 Tivoli Bays

The Tivoli Bays area (Fig.1) comprises >300 hectares of freshwater-tidal shallows and wetlands on the east shore of the Hudson River between Barrytown and Tivoli in the Town of Red Hook, Dutchess County, New York (Kiviat 1974, 1978). The Tivoli Bays are a State Wildlife Management Area (Department of Environmental Conservation), an Experimental Ecological Reserve, and one of four geographic components of the Hudson River National Estuarine Research Reserve (Kiviat et al. 1982). Tivoli South Bay, 120 ha, is separated from the main river by a railroad built on fill in 1850. Three small bridges allow the 1.2 meter tide to exchange through the causeway; South Bay is 1-2 m deep at high tide and extremely shallow water with mudflats at low tide. The Saw Kill, a nontidal perennial stream with a watershed of 68 square kilometers, debouches in South Bay, as do several small nontidal intermittent streams. The bottom of South Bay is soft silty mud with a small area of rocks and gravel in the mouth of the Saw Kill, and a small deeper pool at each railroad bridge. South Bay is bordered on the east and south by 30 m high bluffs of glaciolacustrine silty clay covered with mixed deciduous-coniferous forest. At the north end is a 15 ha stand of wooded tidal swamp separating South and North Bays.

Water-chestnut covers about 87% of South Bay (K. A. Schmidt 1986). Duckweeds and sometimes unidentified filamentous algae exploit the pockets of calm water between water-chestnut rosettes. Some areas around the margins of South Bay are dominated by spatterdock (an emergent water-lily) and pickerelweed. There are small patches of narrowleaf cattail, softstem(?) bulrush, and other emergent species. Before water-chestnut and Eurasian watermilfoil became abundant in the tidal Hudson, the widespread plant communities in sheltered shallows like South Bay were probably dominated by water-celery, pondweeds, naiads, waterweeds, water star-grass, coontail, horned pondweed, and other, mostly native, "submerged" aquatic vascular plants possibly accompanied by charophytes (Muenscher 1935, 1937, McVaugh 1958). Floating-leaved species were rare or absent. (See Table 1 for scientific names.)

Tivoli North Bay (Fig.1) is slightly larger than South Bay, has two instead of three railroad bridges, and its major perennial tributary (Stony Creek) is smaller than the Saw Kill. North Bay is largely (ca 80%) intertidal marsh dominated by narrowleaf cattail, purple loosestrife, spatterdock and arrow arum (Kiviat 1978), but has small subtidal pool and creek habitats with beds of water-celery and watermilfoil, and smaller areas of water-chestnut, and mixed "submerged" aquatics. Outside (west of) the railroad, between Cruger Island and Magdalen Island, is an extensive subtidal shoal dominated by water-celery and watermilfoil.

Tivoli Bays were selected as the study area because of the following heuristic and logistic advantages: 1. They are representative of large, sheltered, shallow, silt-bottom areas of the Hudson between Garrison and Albany; 2. They have a history of ecological research and are well known to us; 3. They are protected for long-term ecological research as part of the National Estuarine Research Reserve; and 4. They adjoin the Bard College Field Station.

2.2 Selection of Sites

Within Tivoli Bays, we selected sites on the basis of dominance by the plant species we wished to study, and accessibility by car-carried canoe. Although more extensive near-monocultures of water-celery and especially watermilfoil have been seen at Tivoli Bays in previous years (Kiviat observations), it was difficult to locate homogeneous stands of any size in 1987. Because stands inside North Bay (east of the railroad, Fig. 1) and outside the bay differed visibly, we chose one stand of each species on either side of the railroad where there was a great enough extent for fish and vegetation sampling.

Because water-chestnut apparently outcompetes submerged species in areas favorable to it, selection of stands of other species *per se* indicates different environmental conditions for plants and presumably for fish as well. Water-chestnut appears to thrive in habitats with softer substrates, slower currents, and less wave energy than the submerged species. We think the submerged species are more tolerant of harsher conditions than water-chestnut and are relegated to these other habitats because water-chestnut has taken over the more sheltered areas like most of South Bay. However, water-chestnut also modifies environmental conditions considerably, making it difficult to separate cause from effect.

2.3 Water-chestnut Site

The water-chestnut site ("T" for *Trapa*) was in a dense water-chestnut bed in Tivoli South Bay in the cove at the mouth of the Saw Kill, and not far from the Bard College Field Station. Area T was ca 65 m from the nearest shoreline to the east and 130 m from the nearest shoreline to the south. It was far enough from shore to be underlain by deep soft mud, but within relatively easy reach of canoe during the period when water-chestnut biomass was extremely obstructive to boat travel. A small subtidal creek bordered area T, and water depths in the area were 0-several cm at low tide and about 100 cm at high tide. Depth at low tide may have been partly due to the large mass of water-chestnut impounding the water, as 1984 observations by Kiviat suggested.

At peak biomass, water-chestnut, with associated duckweeds, almost entirely obscured the water surface from view. Duckweeds comprised a conspicuous but minor component of the neuston in South Bay water-chestnut beds. We found no other vascular plant species at site T, and this is characteristic of well-developed water-chestnut beds in the tidal Hudson River.

2.4 Watermilfoil and Water-celery Areas

Because there was little besides water-chestnut in South Bay and the beds of other species extant in 1987 were not logistically accessible, we sampled water-celery and watermilfoil at sites at Tivoli North Bay 3 km from site T. Accessible near-monospecific beds of these species were small in extent in 1987 and appeared highly variable in shoot density and shoot size. We selected two sites for each species to represent some of this variation as well as different environmental conditions inside North Bay (in "Pool II") and outside the bay in the shallows of the main river (near Magdalen Island).

Water-celery site "VI" (for *Vallisneria* Inside the railroad) was in the eastern end of North Bay Pool II bordering the mouth of the pool's largest tidal creek (tributary IIB) (Fig. 1). The substrate was firm mud sloping into the creek. VI was ca 20 x 20 x 10 m, separated from the willows at the east edge of Pool II by a 6-12 m expanse of spatterdock. There was no apparent vascular vegetation on the deepwater side of the water-celery bed, and on the shallow side there was spatterdock and subulate arrowhead in the intertidal zone. Water depths at low tide were ca 25-70 cm. There were few or no secondary plants.

Water-celery site "VO" (for *Vallisneria* Outside) was about 8 m west of the railroad fill a short distance south of a point due east of the south end of Magdalen Island. This area was a rectangle ca 9 x 18 m. The substrate in this area was level, firm, sandy mud, the coarse sand component evidently fine cinders from the railroad. Water depths at low tide were usually 10-20 cm, occasionally 0 cm. There was a shallow channel between the site and the railroad with very sparse water-celery. A short distance north of the site was spatterdock. There was mixed water-celery and watermilfoil on the south and west, part of a very extensive stand in the shallows between Magdalen Island and the channel at the north end of Cruger Island. The water-celery in VO was conspicuously denser and shorter than in VI, and the water currents were slower in VO. Secondary taxa were not rare in VO although a minor component of the phytomass.

Watermilfoil site "MI" (for *Myriophyllum* Inside) was in the south side of North Bay Pool II. MI was a triangle ca 10 x 10 x 15 m. The substrate was moderately firm mud and nearly level. Water depths were ca 15-35 cm at low tide. This area was surrounded by mixed water-celery and watermilfoil, with spatterdock close on the south. Secondary taxa were as in VO.

Watermilfoil site "MO" (for *Myriophyllum* Outside) was ca 10 m west of the railroad and approximately east of the south end of Magdalen Island. The area was ca 15 m wide from north to south, and 30 m long from east to west. The substrate was firm mud, probably with a small amount of cinder close to the railroad. The bottom was usually more-or-less exposed at low tide with only small puddles of water remaining. MO was bordered by spatterdock on three sides and separated from the railroad by a shallow channel with sparse water-celery. Watermilfoil was shorter in MO than in MI. Secondary taxa were most common in this site but still minor in mass.

Voucher specimens of watermilfoil collected at our sites in 1987 and specimens collected or examined previously at the Tivoli Bays were all identified as Eurasian watermilfoil. Northern watermilfoil could have been present at our study sites, but if so was probably rare compared to Eurasian watermilfoil.

Small areas of the bottom (probably < 2%) of sites MI, MO, VI, and VO were covered by jetsam (e.g., timber, broken glass, coal clinkers, and an occasional rock). During the summer of 1987, no other research and little or no other human activity occurred in our sites.

3 Methods

3.1 Vegetation Sampling

3.1.1 Water-chestnut

We sampled water-chestnut in area T every other week from mid-June to mid-September 1987 (7 sample sets). Plots were located by throwing a sampling frame with eyes closed; this was done anew at each sampling date. Each time all "aboveground" water-chestnut material was harvested from 5 square plots 0.25 m^2 in area by cutting with a shears about 2 cm above the mud surface. Nuts in the mud were not collected; immature and mature nuts attached to rosettes were collected with the rosettes. Rosettes >50% inside the sampling frame were harvested and rosettes <50% inside were not. The long trailing stems were cut at the frame edge as necessary. Harvested material was placed in plastic bags, brought to the Field Station, blotted and wet-weighed on an Ohaus triple-beam balance to the nearest 0.1 g. The total number of leaf rosettes was counted in each sample with the exception of the first two sampling periods. Then the entire sample was cut into 5-cm long pieces with shears, mixed, and a 50-g wet weight subsample taken and dried to constant weight in a Blue M laboratory oven at ca 93C with the top vents open. The subsample dry-wet weight ratios were used to estimate the dry weight of each entire sample.

3.1.2 Water-celery and Watermilfoil

Water-celery is a colonial species with horizontal rhizomes in the substrate bearing well-spaced aboveground shoots (clusters of basal leaves). Eurasian watermilfoil has discrete bushy tufts of leafy stems arising from the substrate. Both species are "submerged" although distal portions of water-celery leaves and watermilfoil leafy stems may trail on the water surface at lower tide stages.

We sampled each species by counting "tufts" (shoots) in 5 thrown 0.25 m^2 plots per site, and randomly selecting two tufts from each plot for harvest. Sometimes we used a sampling frame divided into quarters with cord to facilitate counting plant tufts when it was hard to see the bottom. Tufts were considered independent if separated by 2 cm at the mud surface. If a plot contained fewer than 2 tufts of the dominant species, the harvest of two was made up at random from just outside the plot. Sampling was conducted near low tide when the bottom could be reached easily over the gunwale of the canoe. Harvested tufts were placed individually in plastic bags, returned to the laboratory, measured to the nearest cm of length, weighed wet to the nearest 0.1 g, dried to constant weight and weighed dry to the nearest 0.1 g. At the last sampling period (mid-September), after tufts were counted and two harvested from each plot, the remaining aboveground phytomass was harvested separately from each plot, dried and weighed.

Secondary vascular plant taxa encountered in any water-celery or watermilfoil sampling plot were harvested *in toto* aboveground, brought to the laboratory in plastic bags, weighed wet, dried, and weighed dry. Secondary taxa collected in sampling plots were waterweeds (two species), redhead-grass, and water star-grass.

Water-celery rarely found in watermilfoil sample plots, and *vice versa*, were treated as secondary species and harvested accordingly. Other minor species noted in the sites but not found in sample plots in 1987 were water-chestnut, naiad, coontail, cattail, pickerelweed, and a charophyte (the last a macrophytic alga). (See Table 1 for scientific names.) Kiviat identified all secondary taxa found in the study sites.

Small amounts of dead plant material and sediment adhering to live material were not separated from the phytomass samples before weighing. We restricted the phytomass collection to small numbers of samples in order not to progressively damage the habitats during the course of the season. All vegetation sampling was done near low tide when we could see and reach the bottom.

3.2 Fish Sampling

Sampling fishes from vegetation beds was attempted by three methods. Our goal was to be able to compare species composition and relative abundance among plant communities and over time within communities. Also, we wanted a quantitative estimate of density.

3.2.1 Light Trap

Our primary means of collecting fishes was with a light trap. Our design was modified from Faber (1981). Traps were constructed from 6 mm (1/4 in) Plexiglas. Sides were rectangular (23.4 cm X 15.8 cm) with a recessed slit that allowed fishes and other organisms to enter. The slits varied slightly in size from 10.0-10.3 cm long and from 0.1-0.9 cm wide. Each trap was numbered and the averages for the areas of the slits for each trap were: #1= 5.82 cm^2, #2= 1.92 cm^2, #3= 5.81 cm^2, #4= 3.53 cm^2, #5= 1.51 cm^2, and #6= 2.75 cm^2. Since traps varied, we were very careful to keep track of each trap to determine if some traps were catching more fishes than others. Two slits on each trap were oriented horizontally and two were vertical.

Traps were set into a styrofoam collar so that they floated with the slits below water. Flashlights were strapped onto each trap so that the beam travelled down through the trap. Light was refracted by the Plexiglas and the water so that the whole trap glowed.

Traps were set for a minimum of 25 minutes. The logistics of collecting the traps, however, often meant that some traps were fished longer than others. The time each trap was set and retrieved was noted during sampling. This was especially important since Faber (1981) said that the longer traps were fished, the more specimens were accumulated.

Each trap had a hole cut in the bottom which had a rubber stopper inserted during sampling. When traps were retrieved, a 505 micron plankton net was first put around the trap from the bottom, the trap was lifted partially from the water (the net would catch specimens that might be washed out of the slits), and the stopper was removed, thus flushing all water and organisms out of the trap and into the net. Contents of the plankton net were then transferred to a jar containing full-strength formalin. Addition of the sample diluted the preservative to approximately 10% formalin. Contents of each trap in each vegetation type were kept separate.

In the watermilfoil and water-celery beds, the traps were tied to each other and anchored at one end to keep them from drifting in the current. The cords tying the traps together had snap swivels on each end and were an average of 1.6 m (1.4–1.8) long. Thus the traps sampled a linear patch of vegetation about 8–9 m long. We did not want the traps to be farther apart because, if they were, in some instances, depending on direction of the current, some traps might not be in the vegetation. In the water-chestnut beds, the dense surface growth prevented any drifting, so traps were not tied to each other. They were, however, placed about the same distance apart as in the other vegetation.

3.2.2 Sweep Net

A second fish collecting method utilized a "D"-shaped sweep net on a 120 cm handle. This net had an opening of 93.8 cm^2. Sweep netting was done each time we used the light traps. We would sweep the net once back and forth each of three depths: near surface, half way down the water column, and near the bottom. The path of net movement was ca 2.7 m long, but this distance was shorter at the end of the summer than at the beginning due to vegetation density. We moved the net as quickly as possible through the vegetation. Sweeping was done while the light traps were out but at a distance of 5 m or more which we judged was far enough not to interfere with the light traps. The contents of the sweep net were also preserved in 10% formalin in the field. Since some fish larvae do not have a positive phototactic response and those that do often vary in the magnitude of this response (Faber 1981), we hoped that this method would capture species that were not caught in the light traps.

3.2.3 Wegener Ring

The third sampling method that we tried was a modification of the Wegener ring. Specifically, we wanted a quantitative sampler that would work in dense floating water chestnut mats. The sampler had to be heavy enough to penetrate the water chestnut and isolate a column of water but be manageable from a canoe. We built a prototype using a metal garbage can with the bottom removed as a "ring" and a cloth cylinder attached to the upper end of the ring to isolate the water column. Even though the diameter was small, this device was awkward to use and was not especially successful at catching fishes. Thus we abandoned this sampling method.

3.2.4 General Procedures

When collections were returned to the laboratory, they were sorted and the zooplankton was stored in 50% isopropanol. Fish larvae were transferred to 70% ethanol. They were counted, measured, and identified (Wang and Kernehan 1979, Auer 1982). Schmidt identified or verified the great majority of fish specimens. Zooplankton samples were saved but not analyzed.

Sampling was done approximately once per week. The water-chestnut area was sampled weekly. One watermilfoil site and one water-celery site was sampled each week, the two sites inside the railroad one week and the two sites outside the railroad the next week.

We had to sample the water-celery and watermilfoil beds at or near low tide, otherwise we could not be sure that the light traps were fishing in the vegetation. We could not sample the water-chestnut beds near low tide, however, because it became impossible to move a canoe through the plants at low water. Therefore we sampled when a low tide occurred within up to 4 hr after sunset as close to once a week as we could. All three vegetation beds that were sampled in a week were sampled on the same night.

3.3 Water Quality

During fish sampling (at night), we also measured several water quality parameters in the vegetation beds at each site. Dissolved oxygen and temperature was measured at the surface and near the bottom with a YSI DO meter. Current speed was measured with a Swofford current meter. A surface water sample was taken and returned to the laboratory where pH (Chemtrix pH meter and probe), turbidity (LaMotte BH-3 Turbidimeter), and conductivity (YSI S-C-T meter) were measured.

3.4 Statistical Analyses

3.4.1 Vegetation

Water-celery and watermilfoil sample plot phytomass was estimated as the product of the number of tufts per plot (per site per sampling period) and the mean dry weight per tuft (normally 10 tufts were weighed, but n=9 for three watermilfoil and one water-celery estimates due to missing data). Dry weights <0.1 g of mostly secondary species in the water-celery and watermilfoil samples were considered as 0.1 g for statistical purposes.

We ran a two-way ANOVA (sampling period x site) on the phytomass data, with post-hoc Tukey pairwise comparisons (HSD), using CSS (Complete Statistical System) software on an IBM PC. The mid-June samples were not included in the ANOVA because good watermilfoil samples were not available for this period. This deletion left six sampling periods for ANOVA.

3.4.2 Fish

Statistical analyses were done on the fish data as follows. Because of variation in trap construction, the time each trap was fished was analyzed by a one-way ANOVA to determine if mean times fished differed among traps. Since Faber (1981) indicated a positive relationship between time fished and catch, we did a scatterplot of length of time traps were fished versus number of fish caught. We also did a geometric mean (GM) regression (Ricker 1973) on the number of fish caught versus the number of traps fished for given arbitrary time intervals to determine if a positive relationship might exist.

We did further one-way ANOVA's on the mean time traps were fished in each vegetation type and the mean number of fish caught by each trap to further distinguish possible biases.

Fishes collected in traps and sweeps were compared by a Kendall's tau coefficient which is based on ranking species by abundance. Sizes of larval fish were compared between sampling devices with a Student's t-test. Water quality was compared among sampling sites with one-way ANOVAs.

4 Results

4.1 Vegetation

Fig. 2 shows aboveground phytomass for five sites over seven sampling periods, adjusted to a 1 m^2 basis (note that no watermilfoil samples were taken in the mid-June period, and this period was dropped from the ANOVA). The ANOVA indicated a highly significant difference among sampling periods ($F_5 = 25.3$, $p < 0.00001$) and among sites ($F_4 = 212.3$, $p < 0.00001$), and the sampling period x site interaction was also significant ($F_{20} = 6.2$, $p < 0.00001$).

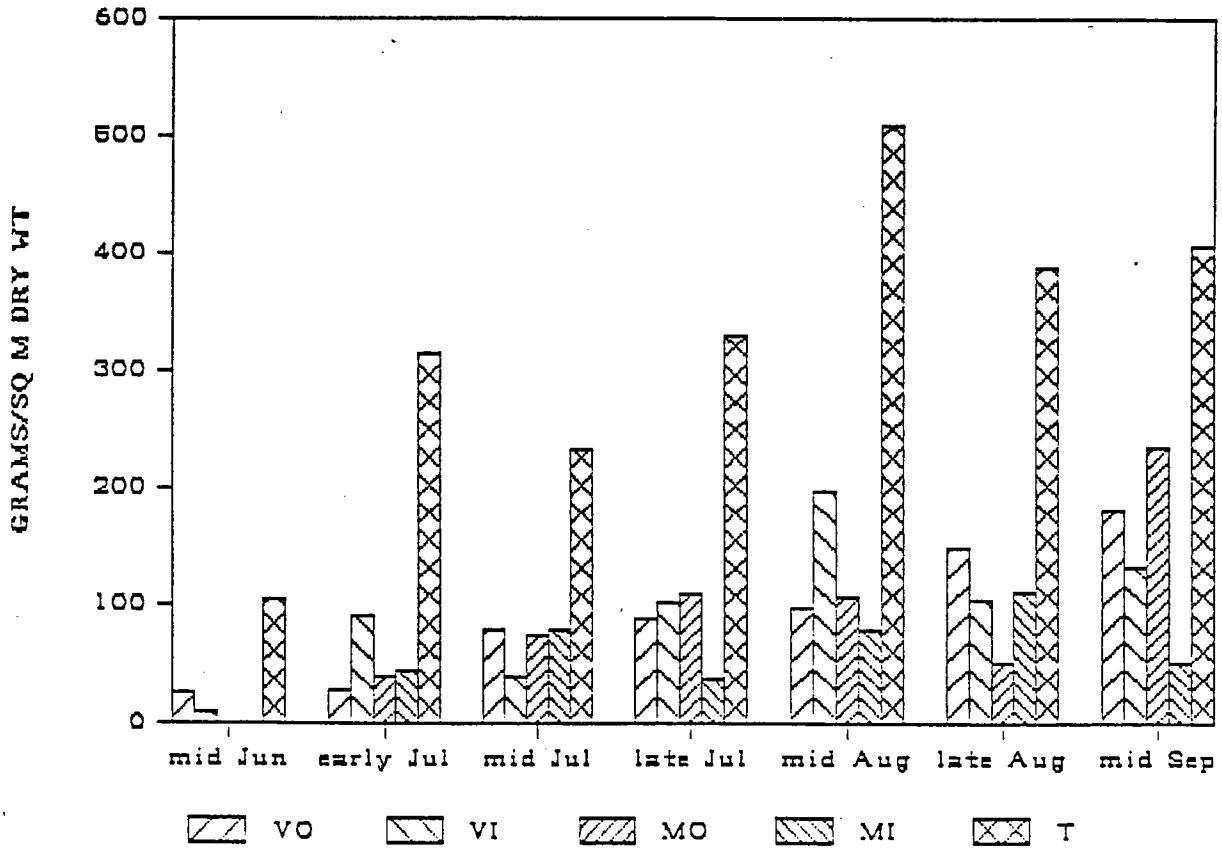


Fig. 2. Aboveground phytomass (g/m^2 dry weight) at five sites and seven sampling periods in 1987. VO = water-celery area outside

railroad, VI = water-celery area inside railroad, MO = watermilfoil area outside railroad, MI = watermilfoil area inside railroad, T = water-chestnut area.

The water-chestnut site (T) supported a higher phytomass than all four other sites throughout the summer (Tukey's pairwise comparisons, $p < 0.05$). Examination of Fig. 2 shows that water-chestnut mass was consistently twice as great as that of water-celery or watermilfoil. A set of mid-summer water-chestnut samples and late summer water-celery and watermilfoil samples from South Bay and North Bay, respectively, in 1984 (Table 2) supports the 1987 phytomass differences between water-chestnut and the other species and we suspect this difference would be found consistently in the fresh-tidal Hudson. Although water-celery and watermilfoil mass appears to vary spatially a good deal (Kiviat, personal observations 1971-87), we think the values in Table 2 are characteristic of patches dominated by these species in the Tivoli Bays area.

There were no significant differences in mass among the water-celery and watermilfoil sites during the first three sampling periods, but from mid-August through mid-September there were occasional differences (Tukey's, $p < 0.05$). MI was greater than MO in mid-August and mid-September, VI was greater than VO in mid-August, VI was greater than MI in mid-August and mid-September, VO was greater than MO in late August, and VO was greater than MI and MO was greater than VI in mid-September.

Among - sampling period comparisons for a single site showed spotty significant differences in phytomass (Tukey's, $p < 0.05$). Water-chestnut mass in mid-August was significantly greater from that in all five other sampling periods, and this appeared to be the time of peak phytomass. Very rapid growth of water-chestnut occurred between mid-June and early July, with the mass of the early July sample significantly greater (Wilcoxon Rank Sum Test, $p = 0.0079$). We did not sample after mid-September, but visual observations indicated a precipitous decline due to senescence and decomposition of water-chestnut rosettes around the end of September.

There were no significant differences among sampling periods for site MI. For site MO, mid-September mass was significantly greater than all five other sampling periods; also, mid-August mass was greater than that in either late July or early August. For site VI, mid-August mass was greater than early July, mid-July, late July and late August. For site VO, mid-September mass was greater than mass in any sampling period from early July to mid-August. Thus, for the water-celery and watermilfoil sites outside the railroad (VO and MO, respectively), mid-September was the period of peak phytomass, but for the water-celery site inside the railroad (VI) mass peaked in August. The higher-energy environment outside the railroad, with exposure to larger wind waves and shipping wakes, may retard the growth potential of these species so that steady growth occurs through the summer rather than more rapid growth to a peak followed by a decline as appears to have occurred at sites VI and T.

In 1987, we did not examine the partitioning of phytomass among plant organs. In the set of 10 water-chestnut samples taken in South Bay in 1984, however, rosettes and stems averaged 63% and 37%, respectively, of the aboveground phytomass.

We did not measure the phytomass of duckweeds in area T in 1987, but duckweeds accounted for 0.03-2% of the total sample dry weight in the 1984 sample of water-chestnut from South Bay. This indicates a minor component of the phytomass in South Bay that could be significant to fish. Duckweeds accumulate between the water-chestnut leaves on the calm waters of South Bay but are absent in beds of water-celery and watermilfoil that lack continuously-floating organs.

In the other 1987 sites (MI, MO, VI, VO) there were minor components of the phytomass in secondary "submerged" plant species. These species accounted for 0-18% of individual water-celery area samples, and 0-17% of watermilfoil samples. Twenty-one of 30 MO samples, 18 of 35 VO, 3 of 30 MI samples, and 1 of 35 VI samples contained secondary species. Secondary species represented in these samples were Canadian and Nuttall's waterweeds, perfoliate pondweed, water star-grass, watermilfoil and water-celery (the last two in plots of the opposite species). Observed rarely in the water-celery and watermilfoil sites but not represented in samples were water-chestnut, naiad, cattail, and a charophyte.

Table 2. Aboveground phytomass of water-chestnut, water-celery, and Eurasian watermilfoil communities in Tivoli Bays 1984 and 1987 (g/m^2 dry weight, rounded to the nearest 1 g).

	1984		1987	
Species	Range	Mean	Range	Mean
Water-chestnut	268-455	892 (a)	190-428	330 (d)
Water-celery	47-234	138 (b)	130-232	198 (e)
			96-189	150 (f)
Watermilfoil	46-294	138 (c)	0-174	113 (g)
			32-70	52 (h)

a South Bay, 25 July 1984; n=10; all samples contained 0.03-2% duckweeds.

b North Bay inside railroad, 20-23 August 1984; n=13; all samples were monospecific except three which contained 0.4-4% secondary submerged species.

c North Bay inside railroad, 21-23 August 1984; n=15; all samples were monospecific except three which contained 1-13% secondary submerged species.

d South Bay (area T), 28 July 1987; n=5; duckweeds not measured, no other secondary species.

e North Bay inside railroad (VI), 18 August 1987; n=5; 0% secondary species.

f North Bay outside railroad (VO), 26 August 1987; n=5; four samples contained 0.9-3% secondary species.

g North Bay inside railroad (MI), 26 August 1987; n=5; one sample contained 5% secondary submerged species.

h North Bay outside railroad (MO), 31 August 1987; n=5; four samples contained 1-12% secondary submerged species.

Table 3. Density counts of dominant plant species in phytomass samples, all sampling periods combined 1987. See Table 2 for explanation of site codes.

Species	Site	Range	Mean
Water-chestnut	T	3-12	8.7
Watermilfoil	MI	0-7	3.0
	MO	1-13	7.0
Water-celery	VI	9-53	29.6
	VO	18-64	36.6

Density data are shown in Table 3. These are rosette counts for water-chestnut, shoot (ramet) counts for water-celery, and "tuft" (tuft of stems, probably an entire plant) counts for watermilfoil, all per 0.25 m^2. For all species, counts included units of any size no matter how small. Densities were visibly lower in MI and VI than in MO and VO, respectively. Densities seemed to increase gradually through the sampling season in VI, VO, and MO, but to remain the same or decrease slightly in MI. The watermilfoil sites (MI, MO) had very low density and lots of empty space at substrate level. Density data were not analyzed statistically.

The water-chestnut mean dry weight / wet weight ratio, for 3 sets of 5 samples each from Tivoli South Bay, 28 July to 31 August 1987, was 0.0775. Ratios for 50 g subsamples from individual 0.25 m^2 samples (mid-June to mid-September) varied from 0.066 to 0.214.