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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

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1. 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*

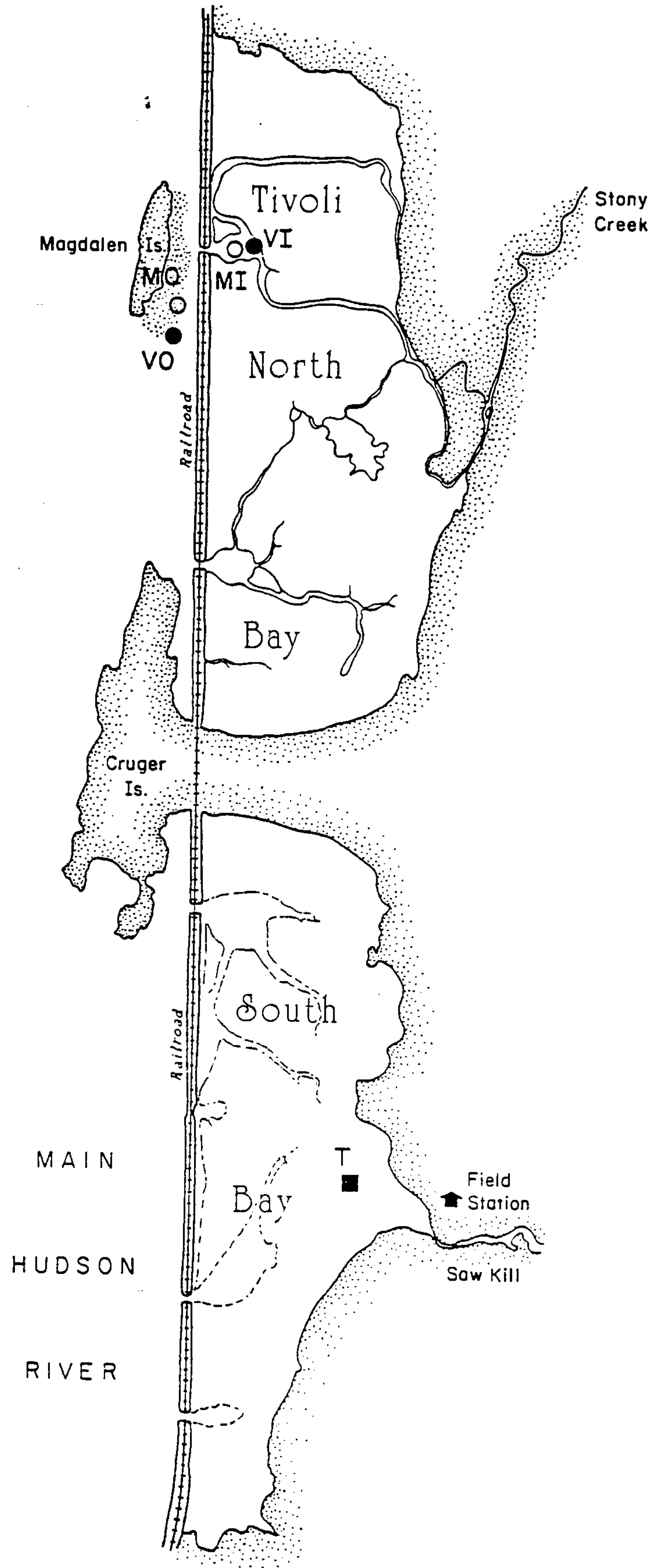
a One or more of the following species: *Lemna minor*, *Spirodela polyrhiza*, *Wolffia* sp.

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).