HUDSONIA

# *Invasive Species Threats to Rare Plants in the Hudson River Tidal Wetlands: Analysis and Recommendations*

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*Yellow iris (nonnative)*

*New England bulrush (native)*

## Introduction

Rare native plants have many values to human society and to the ecosystems in which they occur. For example, common and rare species alike may provide natural products with pharmacological potential, as a large number of plants has done in the past. Many other material and non-material benefits to human society exist. Because of the ecosystem services provided by plant diversity (see Isbell et al. 2011 for grasslands), conservation scientists and preserve managers are interested in the conservation of rare plants and their habitats. Unfortunately, many rare native species have been studied little, and this may be especially true of estuarine plants (e.g., Padgett et al. 2004).

Many rare native plant species of conservation concern occur in coastal areas of North America, and the shoreline belt below the 3 m elevation contour is especially important for rare species including Long's bittercress (Reid and Trexler 1992). The tide-affected habitats of the Hudson River have been known for many years as a plant diversity and rare species hotspot (Mitchell and Sheviak 1992). Much concern has been raised since at least the 1990s about the potential effects of nonnative weeds on plant diversity in the Hudson River and other East Coast estuaries (e.g., Kiviat 2009). Variable efforts have been applied to managing the European lineage of common reed (*Phragmites australis* ssp. *australis*), and water-chestnut (*Trapa natans*), in Hudson River tidal marshes, in part because of their impacts or potential impacts on native plants.

Although many ecologists and managers agree that invasive species are a threat, or potential threat, to rare native plants, there is insufficient science-based guidance about distinguishing which native species are affected and to what degree, and how to target management to reduce the threats. Tidal wetlands and associated estuarine and shoreline habitats are ecologically sensitive places with many values in addition to rare plants and animals, and there are often centers of human population (that generate impacts and consume services) close to these rare plant habitats. Techniques for managing nonnative species are somewhat crude, and can cause mortality or morbidity of associated native species of plants, animals, and other organisms. For example, glyphosate and glyphosate-based herbicides, the tools most often used for control of common reed and many other nonnative weeds, are toxic to mammals (e.g., Richard et al. 2005, Thongprakaisang et al. 2013, Kumar et al. 2014) and nontarget plants. The classical biocontrol program under development for nonnative common reed is a threat to the native lineages of common reed and the native insects and other native organisms that use reed habitats or eat reed (Kiviat 2013, Cronin et al. submitted).

Nonnative species do not affect all rare native plants adversely, and many nonnative species are not a threat to rare natives. Therefore it is important to discern which interactions are negative for rare plants, and which stands of rare plants are the most able to be conserved and managed in the long term. Discovering this information can take years of monitoring for which funding and expertise are rarely available. The aim of our study was to develop indicators of the negative effects of nonnative plants upon rare native plants that could serve to focus attention on those rare species most promising for conservation and those nonnative weeds that seem to present the greatest potential threats. We assessed threats to rare native plants associated with potential spread and overgrowth by nonnative weeds using metrics of vigor and competitiveness. It should be noted here that there are many ecological definitions of, and types of, competition (e.g., Keddy 1989, Grace and Tilman 1990. We are not attempting to equate our consideration of "competition" to any formal definition or proof of ecological interactions. Nonetheless we are assuming that there is at times a greater or lesser degree of potential negative effect of certain nonnative weeds on certain rare native plants, although we do not necessarily know that invasive weeds are the principal reasons for the scarcity or decline of the rare natives.

We conducted this study beginning with documented occurrences of rare native plant species in tidal wetlands of the Hudson River. We then made observations and measurements of the potential relationships of those rarities with nearby nonnative weeds. We also discuss certain species of nonnative animals that are potential threats to rare plants, although we did not study those animals in the field.

## Methods

We began by mapping Hudson River rare plant locality data, using ArcGIS 10.2, from an ongoing New York Botanical Garden study, the New York Natural Heritage Program, Hudsonia knowledge, and other sources. These occurrence data were overlaid on orthophotography base maps of the tidal wetlands to guide us to the rare plants in the field. We used orthoimagery from Dutchess, Orange, Putnam, Rockland, Ulster, and Westchester counties, obtained from the New York State GIS Clearinghouse. All was 2013 4-band, 12-inch imagery, with the exceptions of Westchester (2009 4-band, 12-inch) and Rockland (2013 4-band, 6-inch). We used phenology data from the New York Natural Heritage Program (http://www.acris.nynhp.org/plants.php) to schedule field visits to particular wetlands so as to maximize the probability of detecting and identifying the rare species when they were in flower or fruit (as appropriate). We conducted literature searches on the rare species known to occur in the Hudson River, and communicated with experts who have studied certain species.

We focused on the 14 major ( > 5 ha) tidal wetlands (Table 1) in the Lower Hudson PRISM region from Saugerties south to Piermont, where most of the previous work on rare plants had been conducted. We visited each wetland complex 1-4 (typically 1-2) times by canoe for ca 6 hours of a low tide period. A few locations were accessed on foot for shorter periods. In each visit we searched for one or more rare plants that had been mapped to that location by previous field workers. Our field visits were timed, as much as possible, to the phenological periods when particular species were detectable and identifiable. Because critical identification of *Bidens* spp. requires mature achenes that are often not available until September, and some of the other species are still identifiable in late summer and early fall, we conducted much of the field work in September-October.

At each rare plant occurrence that we located, we recorded UTM coordinates with a handheld Garmin GPS unit. We searched for all nonnative plants within 10 m of the rare plant stand, regardless of habitat. Although we had intended to observe the most invasive species (e.g., common reed) within 50 m of each rare plant, limited ability to see and move around rendered this objective unworkable. For each rare plant occurrence (stand), we measured or estimated several metrics (Table 2) believed indicative of vigor, aboveground biomass, or competitiveness. We recorded the same metrics for each stand of a nonnative weed (invasive plant) no farther than

10 m from the rare plant stand. In addition we measured the distance between the rare plant stand and the weed stand.

Table 1. Hudson River tidal wetlands studied, with river kilometer (above the Battery) and east or west shore location. RR = active railroad borders wetland. Some of the sites are 2-3 km long.

| **Site name** | **River kilometer** | **E or W, RR** |
|---|---|---|
| Saugerties Marshes | 165 | W |
| Tivoli Bays (North Bay, Cruger Island, South Bay) | 161 | E – RR |
| Kingston Marshes (including Kingston Point and Sleightsburg Spit) | 149 | W |
| Vanderburg Cove (including tidal Fallsburg Creek and tidal Landsman Kill) | 143 | E – RR |
| Fishkill Creek | 97 | E – RR |
| Constitution Marsh | 83 | E – RR |
| Con’s Hook | 79 | W – RR |
| Manitou Marsh | 75 | E – RR |
| Iona Island Marsh | 74 | W – RR |
| Haverstraw Marshes | 63 | W - RR |
| Croton Marshes | 55 | E – RR |
| Piermont Marsh | 39 | W |

Plant height or length is often regarded as indicative of vigor or aboveground biomass. Kawano et al. (1974) regarded height as a good indicator of competitive ability in cultivated rice (*Oryza*). Zhao et al. (2012) recorded density, height, and diameter of culms as indicators of sugar cane (*Saccharum*) vigor. Rice and sugar cane are giant grasses. Fenster et al. (2006) used stem length as a vigor indicator for fire pink (*Silene virginica*), a forb. Pyšek et al. (1995) found that herb species with greater maximum height were more likely to be invasive in seminatural habitats of the Czech Republic. Keddy and Shipley (1989) regarded greater height as conferring competitive ability in general.

We considered stand density (numbers of shoots per unit area) indicative of stand vigor, whether a stand was clonal (e.g., common reed or cattail) or composed of discrete individuals or clumps (e.g., purple loosestrife or yellow iris). The more dense a stand, the more biomass it contains (other things equal) and the less resources there are for other species. Stand area indicates past success and current tenacity of the species at the particular site. Although many marsh plants reproduce vegetatively, by rhizomes, fragments, or other means, flowering and fruiting nonetheless indicate the ability of the species to occupy vacant or new microhabitats, and create more individuals or stands to compete with other species.

We recognize that plant shoots may be long and thin (“leggy”) when they are starved for light, and that some plants may flower and fruit more when conditions are imperfect. However, we saw few if any native or nonnative plants that seemed abnormal or stressed in those respects. Our firsthand knowledge of the Hudson River tidal wetlands indicates that the shoots and stands we studied in this project were more-or-less normal for this environment.

Many other indicators, such as leaf area, aboveground biomass, and number of flowers or fruits have also been used, but measurement of these was beyond the scope of the current project. Reduction of biomass (disturbance) often facilitates plant invasion (Cronk and Fuller 1995:33), although, as we point out below, certain rare native species are exploiters of disturbance. Most of the rare plants we studied have long flowering-fruiting seasons in the marshes, but it is still possible that we missed early fruiting when we sampled late in the season (e.g., Long's bittercress). The flowering-fruiting metric is downweighted (only 1 point) to accomodate this possibility as well as that some of the most robust nonnative weeds (common reed, cattail, yellow iris, sweetflag) tend to spread and compete vegetatively more than by establishment from seed.

Table 2. Observations recorded about rare plant stands and nearby invasive plant stands.

| **Metric** | **Description** |
|---|---|
| Stand size | Estimated linear dimensions of stand in meters; product is the stand area in $m^2$. Truncated at 100 $m^2$ if larger. |
| Density | Rated as Low (sparse), Medium, or High (dense) |
| Shoot length | Maximum stretched length of shoots measured to the nearest centimeter (stretched length is a more repeatable measurement than height in the natural position of the shoot). |
| Flowering or fruiting | Whether or not flowers or fruits are present at the time of survey |
| Intertidal zone level (IT) | Subtidal (below Mean Low Water = mean low tide level), Lower intertidal (lower third of intertidal zone), Middle intertidal (middle third), Upper intertidal (upper third), or Supratidal (from Mean High Water to 1 m above MHW vertically. Estimated from observations of water levels, high water mud marks on plants, high water wrack lines, and presence of species indicative of levels (e.g., *Nuphar* grows mostly in lower intertidal, *Typha* mostly in upper intertidal). |
| Perimeter (rare stand only) | Percentage of perimeter of rare plant stand bordered (within 1 m distance) by common reed, cattail, and purple loosestrife combined, estimated visually (not included in the competitiveness index, see below) |

We developed a simple additive "competitiveness" index based on vigor metrics, distance between rare plant and invasive plant, and relative intertidal elevations. This index is intended to rate the ability of each rare native species, and nonnative weed, respectively, to hold its own, spread, and compete with other plants. (We constructed the index only for the weed species having greater invasive potential.) First we transformed the shoot length, stand area, and density rating to ranks (Table 3) to put all variables on the same scale. Then we constructed the index as

$$C = LR + SR + DeR + F$$

where C is the competitiveness index, LR is the shoot length rank, SR is the stand area rank, and DeR is the density rank. F is either 1 or 0, for presence or absence of flowers-fruits. Intertidal zone level (IT) was ranked as: 0 = subtidal, 1 = lower intertidal, 2 = middle intertidal, 3 = upper intertidal, and 4 = supratidal. We also calculated the difference in IT by subtracting the rare species IT from the weed IT. This was also converted to ranks (Table 3). We incorporated the difference of ranks into the competitiveness indices for the major nonnative weeds. We also incorporated the distance between rare native and weed into the index for the weed in that sample. Because C for the weeds incorporated these two additional variables (distance and elevation difference), the C values are increased by roughly 7-10 points above the C values for the rare species. While this competitiveness index is additive, a different weighting of its component metrics, or a multiplicative index, might be worth exploring.

Table 3. Ranking system for plant stand metrics. Ranks can have half-steps.

| | **Rank** | | | | |
|---|---|---|---|---|---|
| **Metric** | *1* | *2* | *3* | *4* | *5* |
| Stand area, $m^2$ | 0.1-5 | 6-20 | 21-50 | 51-99 | ≥100 |
| Shoot length, cm | ≤10 | 11-50 | 51-150 | 151-250 | 251-400 |
| Density | Low | Low-Medium | Medium | Medium-High | High |
| Difference in intertidal zone level | 4 | 3 | 2 | 1 | 0 |
| Distance, m | 8-10 | 5-7.9 | 3-4.9 | 1-2.9 | 0-0.9 |

For the purposes of this study we considered sweetflag (*Acorus*), cattail (*Typha angustifolia* and *Typha* × *glauca*), bindweed (*Calystegia sepium*), reed canary grass (*Phalaris arundinacea*), and common reed (*Phragmites australis*) nonnative (invasive) species. Some of these taxa have both native and nonnative forms, or their origin(s) is debated. As far as is known, all Hudson River estuary common reed is the European lineage or subspecies *P. australis australis* (Saltonstall 2002 and unpublished data). See Tables 4 and 5 for scientific and common names of all rare native plants and nonnative weeds studied.

We performed statistical and graphical data analyses using Statistica version 12 (StatSoft, Tulsa, Oklahoma) with α set at 0.05. Nonnative plant species occurrences are being reported to iMap Invasives New York (http://www.nyimapinvasives.org/). Rare species location data and all other raw data will be deposited with Lower Hudson PRISM and other appropriate institutions. Voucher specimens of selected species of nonnative weeds and rare native plants have been deposited in the herbarium of the Bard College Field Station – Hudsonia. Photographic vouchers of many of the rare plant species have been deposited at Hudsonia and in the personal collection of Erik Kiviat.

## Study Sites

The Hudson River study area is an estuary with bimodal tides (high-low-high-low in about 25 hours). The mean tide range (vertical distance between Mean High Water and Mean Low Water) is about 1.2 m at Tivoli, 0.82 m at Constitution Marsh, and 0.98 m at Piermont, according to the U.S. Geological Survey topographic map sheets. A general description of Hudson River tidal wetland vegetation is in Kiviat et al. (2006).

We studied 12 major tidal wetland complexes in the LH PRISM region, from Saugerties south to Piermont (Table 1). Two additional marshes, Marlboro Marsh and Moodna Marsh, were omitted because there were no rare plant records from Marlboro and only dwarf *Sagittaria*, for which we had plenty of samples elsewhere, from Moodna. The marshes from Saugerties to Fishkill Creek are normally freshwater tidal (although Fishkill may be very slightly brackish during droughts). Constitution Marsh reached 2 ppt (parts-per-thousand) salinity in the drought of late summer 2015 (David Decker, pers. comm.). Maximum salinity at Piermont Pier was ca 17 ppt in late September (HRECOS 2015; summer and fall 2015 were very dry hence greater salinity intrusion). Salinity was near zero at Piermont in late April 2015 (HRECOS 2015).

## Results

We located 45 occurrences (stands) of 15 rare native species (Table 4) including 1 regionally-rare cordgrass. Although saltmarsh fleabane (*Pluchea odorata*) and tidewater-hemp (*Amaranthus cannabinus*) were included in the rare plant data we received, we omitted those species from our surveys because the latter is common throughout, and the former is common in the brackish marshes (and both species are colonizers of disturbance in tidal marshes). We did not search for strap-leaved arrowhead because it is locally common in most of the marshes, although we did sample it where we found it with other species of interest.

### *Upriver-downriver relationships*

We examined certain along-river, site-level factors as context for the rare plant – weed relationships. Common reed cover (areal dominance of the upper elevation marsh) increased downriver (Fig. 1), based on data from Findlay et al. (2014) compiled from 2007 DEC airphotos. Weed species richness (the number of nonnative weeds we found within 10 m of a rare species) increased upriver (Fig. 2), perhaps because fewer species tolerate brackish water and perhaps also because less of each marsh was reed-dominated upriver thus there was more space for other weeds.

Table 4. Rare plants studied. Rank = New York Natural Heritage Program state rank (explorer.natureserve.org); R = Rare, T = Threatened, E = Endangered (New York State listings); O = Number of occurrences in the study; L = Maximum length in cm; S = Stand area in $m^2$, truncated at 100; D = Density of stand from 1 sparse to 3 dense; IT = Intertidal zone level from 1 lower intertidal to 3 upper intertidal.

| **Scientific name** | **Common name** | **Rank** | **O** | **L** | **S** | **D** | **IT** |
|---|---|---|---|---|---|---|---|
| *Bidens bidentoides* | Estuary beggarticks | S3 R | 2 | 85-100 | 100 | 1-2 | 3 |
| *Bidens laevis* | Smooth bur-marigold | S2 T | 2 | 130-147 | 100 | 1-2 | 2-3 |
| *Bolboschoenus novae-angliae* | New England bulrush | S1 E | 6 | 160-283 | 100 | 1-3 | 2-3 |
| *Cardamine longii* | Long's bittercress | S2 T | 1 | 6 | 100 | 1 | 3 |
| *Cyperus flavescens* | Yellow flatsedge | S1 E | 1 | 49 | 100 | 2 | 3 |
| *Heteranthera reniformis* | Kidney-leaved mud-plantain | S3 | 3 | 6-32 | 1.5-100 | 1-2 | 1.5-2 |
| *Lilaeopsis chinensis* | Lilaeopsis | S2 T | 2 | 3-4 | 7-100 | 3 | 2.5 |
| *Limosella australis* | Mudwort | S3 | 3 | 3-7 | 100 | 2-3 | 1.5-2 |
| *Najas guadalupensis muenscheri* | Hudson River water-nymph | S1 E | 1 | 5 | 100 | 1 | 1 |
| *Orontium aquaticum* | Goldenclub | S2 T | 3 | 50-80 | 3-100 | 1-3 | 1.5-3 |
| *Plantago cordata* | Heart-leaved plantain | S3 T | 3 | 30-65 | 0.8-100 | 2 | 2.5-3 |
| *Sagittaria montevidensis spongiosa* | Spongy arrowhead | S2 T | 7 | 4-9.5 | 100 | 1-3 | 1-2 |
| *Sagittaria subulata* | Strap-leaved arrowhead | S3 | 6 | 4-8 | 4-100 | 1-3 | 1-2 |
| *Spartina cynosuroides* | Tall cordgrass | Regionally rare | 2 | 190-238 | 40-60 | 1-3 | 2.5-3 |
| *Symphyotrichum subulatum* | Saltmarsh aster | S2 T | 3 | 89-120 | 40-100 | 1-3 | 2-3 |

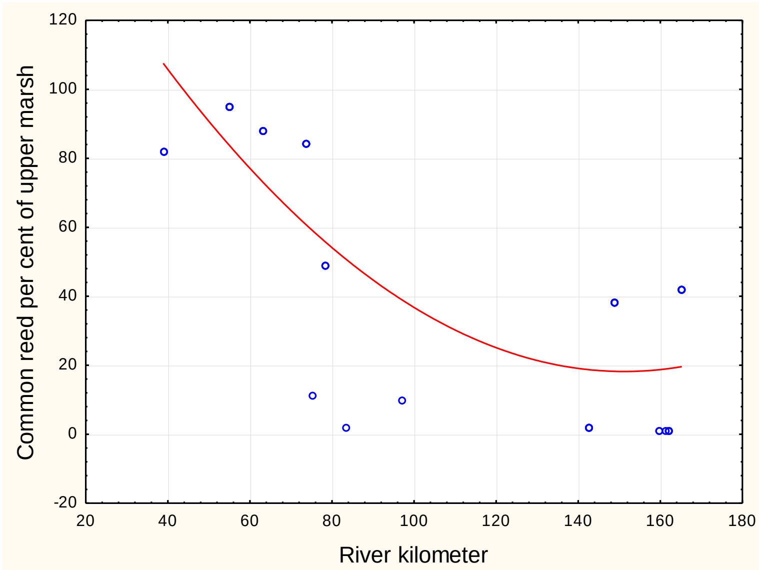


Figure 1. Common reed cover of upper elevation marsh (upper intertidal – low supratidal) vs. river kilometers north of The Battery. Fit line is polynomial. Spearman rank-order correlation: rho = - 0.750, p = 0.000000.

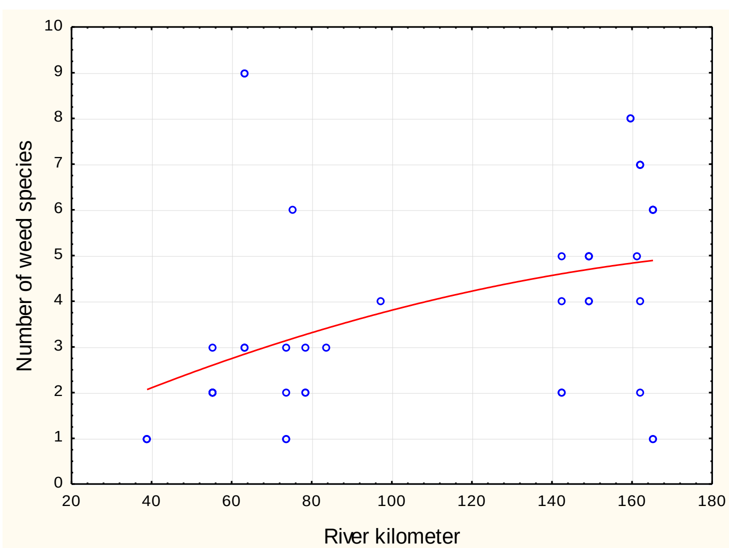


Figure 2. Weed species richness vs. river kilometer. Fit line is polynomial. Spearman rank-order correlation: rho = 0.459, p = 0.00152.

*Characteristics of the rare native plant stands*

Table 4 (above) presents data on the rare plant occurrences (stands) we studied. The great variation in shoot length is noteworthy. Also, many stands exceeded 100 $m^2$ and were truncated for analysis. We did this because we could not consistently see or explore larger areas due to tall dense vegetation, tidal creeks, soft mud, and other hindrances. Most rare plant stands were of low or medium density, and many were situated at lower or middle intertidal levels.

Certain rare native plant stands seem noteworthy because they have large numbers of shoots, large stand area, many juvenile plants, or were fruiting abundantly. Among noteworthy stands were the heart-leaved plantain, strap-leaved arrowhead, and spongy arrowhead at Saugerties, New England bulrush at Con's Hook, and the saltmarsh aster and yellow flatsedge at Iona Island. At the same time, some rare plant stands are declining (e.g., heart-leaved plantain in Tivoli North Bay). Historical data do not always permit determination of increase, stability, or decline.

There were many stands we were unable to locate (e.g., saltmarsh aster at Constitution Marsh). Although smooth bur-marigold was mapped extensively in Tivoli North Bay, we only found plants that were morphologically closer to nodding bur-marigold (*Bidens cernua*) than to smooth bur-marigold. Certain other species have not been documented in the Hudson River in many years (e.g., estuary hatpins [*Eriocaulon parkeri*]). One species, Nuttall's micranthemum (*Micranthemum micranthemoides*), endemic to freshwater tidal marshes of the East Coast and once present in Tivoli North Bay, has not been seen in several decades and is believed extinct rangewide. We found several rare plant stands that apparently had not been documented previously, including New England bulrush at Haverstraw, Piermont, and Manitou (the last two were sterile and in need of species verification), Long's bittercress at Vanderburg, goldenclub at Cruger Island (Tivoli), and smooth bur-marigold at Tivoli (South Bay). We found spongy arrowhead much more extensive at Sleightsburg Spit (Kingston) than previously documented. Although we became aware of its rare native status too late for a formal sample, we also discovered false-daisy (*Eclipta prostrata*) at Kingston.

*Characteristics of the nonnative weeds*

The thirty taxa of nonnative weeds (as defined for this study; Table 5) constituted 2 trees, 3 shrubs, 2 subshrubs (woody at the base and herbaceous above),  6 vines, 1 shrub-vine, 7 forbs, 7 graminoids, 1 floating-leaved aquatic and 1 submergent aquatic. Although multiflora rose is commonly considered a shrub, it clambers 4 m or higher into trees by means of recurved prickles, giving it vine-like properties.

Purple loosestrife stands near the rare plants were less dense and had lower competitiveness indices than common reed or cattail stands, and the last two were similar in density and competitiveness index (Figs. 3-4). The increasing order of length was purple loosestrife, cattail, common reed (Fig. 5). Purple loosestrife has been declining in abundance and density in at least some of the Hudson River marshes (including Tivoli Bays and Iona Island Marsh) since the 1970s, and some of this decline occurred prior to several yearsa ago when the golden loosestrife beetles (*Galerucella pusilla* or *G. calmariensis*) released for biological control first established in the tidal marshes at Tivoli (E. Kiviat, pers. obs.).

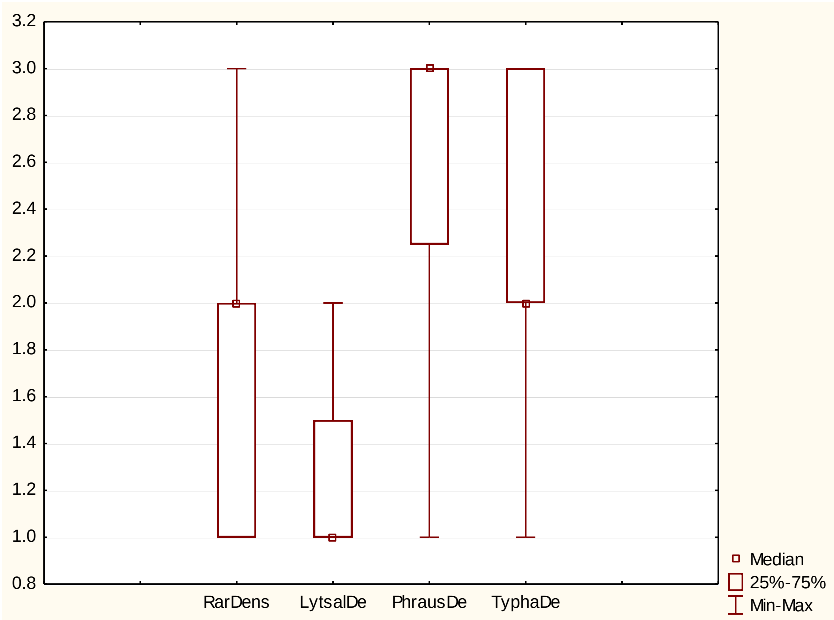


Figure 3. Density ratings of rare native plants, purple loosestrife, common reed, and cattail (left to right).

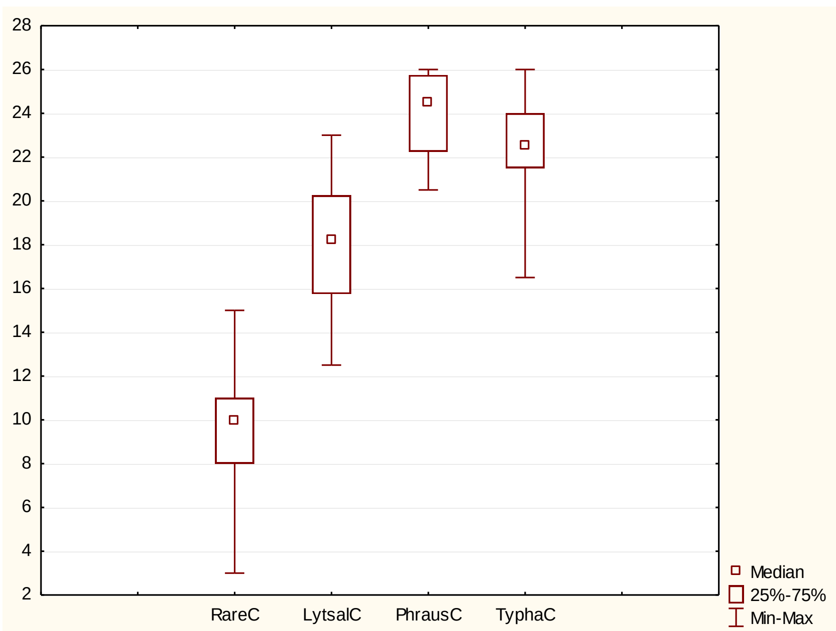


Figure 4. Competitiveness indices for rare native plants, purple loosestrife, common reed, and cattail (left to right). Competitiveness index is the sum of ranked shoot length, density, and stand area, plus a point for flowering or fruiting. Distance between weed and rare native, and difference in elevation, are also calculated into the competitiveness indices for the weeds, artifically increasing the index compared to the rare species.

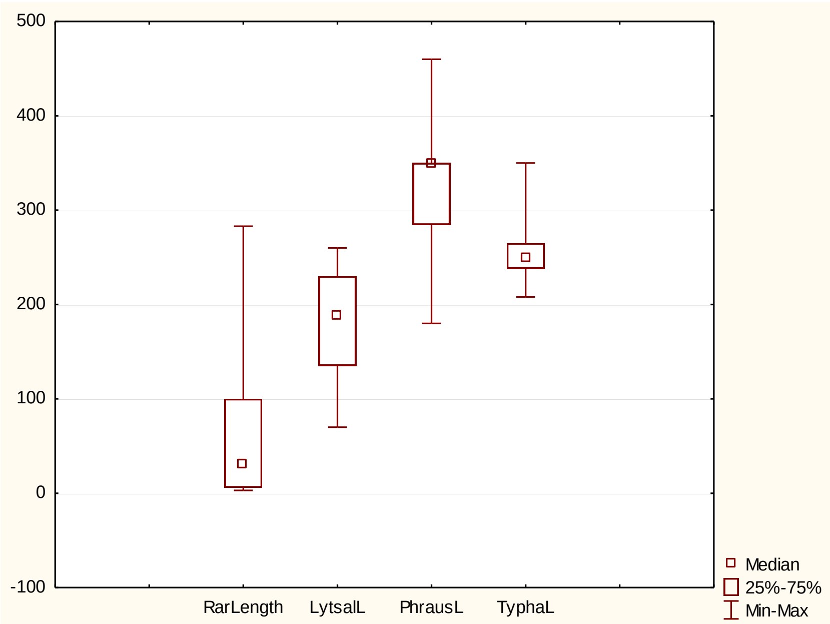


Figure 5. Lengths of rare native plants, purple loosestrife, common reed, and cattail (left to right).

*Rare plant – weed relationships*

Table 5 lists the species of nonnative weeds near rare native plants in our samples, with numbers of occurrences, growth habit, and mean competitiveness indices. It is obvious (Table 6) that the principal nonnative weeds have higher competitiveness indices than the nearby rare native plants, and this is true after adjusting for the additional variables in C for the weeds. We found common reed and purple loosestrife each within 10 m of 20 different rare native species (of 45 rare natives sampled), and cattail within 10 m of 19 rare natives.

Many of the rare plant stands occurred at intertidal zone levels between the potentially most competitive weeds above and below (Fig. 6). Rare plants growing at higher tidal elevations have more of the perimeter occupied by robust weeds (rho = 0.304, p = 0.0427). These analyses suggest that differences in intertidal level (elevation) help to protect rare native species from nonnative weeds in some cases. Certain weeds that occur mostly in the supratidal zone, such as false-indigo, are unlikely to threaten the rare native intertidal species.

Table 5. Nonnative weeds within 10 m of rare native plants with number of rare plant occurrences (samples, "Occurrence"). Three taxa, *Acorus, Calystegia sepium,* and *Typha*, are of uncertain origin. Growth habit: t = tree, s = shrub, v = vine, fs = subshrub, f = forb, g = graminoid, a = submergent aquatic, l = floating-leaved aquatic. Major weed species (n = 10) are those that occurred in more samples or which have greater potential for spread based on data from other habitats; C = mean competitiveness index is shown for each of these taxa. Note that C for weeds are biased upwards (compared to C for rare natives) because the former incorporates two additional metrics, distance and elevation difference.

| **Scientific name** | **Common name** | **Habit** | **Occurrences** | **C** |
|---|---|---|---|---|
| *Acorus* | Sweetflag | g | 7 | 19.36 |
| *Amorpha fruticosa* | False-indigo | s | 9 | 19.22 |
| *Ampelopsis brevipedunculata* | Porcelainberry | v | 1 | |
| *Artemisia vulgaris* | Mugwort | f | 2 | |
| *Berberis thunbergii* | Japanese barberry | s | 3 | |
| *Calystegia sepium* | Bindweed | v | 3 | |
| *Cardamine impatiens* | Narrow-leaved bittercress | f | 1 | |
| *Celastrus orbiculatus* | Oriental bittersweet | v | 3 | |
| *Clematis terniflora* | Autumn clematis | v | 2 | |
| *Cynanchum louiseae* | Black swallowwort | v | 1 | |
| *Hemerocallus fulva* | Day-lily | g | 1 | |
| *Iris pseudacorus* | Yellow iris | g | 14 | 17.82 |
| *Lonicera* X *bella* | Bell's honeysuckle | s | 4 | |
| *Lonicera japonica* | Japanese honeysuckle | v | 2 | |
| *Lycopus europaeus* | European bugleweed | f | 1 | |
| *Lythrum salicaria* | Purple loosestrife | fs | 20 | 17.93 |
| *Melilotus* | Sweet-clover | f | 1 | |
| *Microstegium vimineum* | Stiltgrass | g | 4 | 18.38 |
| *Myriophyllum spicatum* | Eurasian watermilfoil | a | 20 | 17.85 |
| *Pastinaca sativa* | Wild parsnip | f | 2 | |
| *Phalaris arundinacea* | Reed canary grass | g | 1 | 18.50 |
| *Phragmites australis* | Common reed | g | 20 | 24.10 |
| *Polygonum cuspidatum* | Japanese knotweed | fs | 1 | |
| *Polygonum hydropiper* | Water-pepper | f | 1 | |
| *Rosa multiflora* | Multiflora rose | s/v | 11 | 17.77 |
| *Rumex crispus* | Curly dock | f | 2 | |
| *Salix ?alba* | White willow | t | 2 | |
| *Trapa natans* | Water-chestnut | l | 6 | 17.67 |
| *Typha* | Cattail | g | 19 | 22.66 |
| *Ulmus* (nonnative species) | Elm | t | 2 | |

Table 6. Rare native species with rare species competitiveness index (C), competitiveness indices of the two associated weeds with the highest C, and rank of difference in intertidal level (D) between the rare species and each associated weed from 0 greatest difference to 5 no difference. Weed abbreviations: *Acorus* (sweetflag), *Amofru* =*Amorpha fruticosa* (false-indigo), *Cynlou* = *Cynanchum louiseae* (black swallowwort), *Fal* = *Fallopia japonica* (Japanese knotweed), *Iripse* = *Iris pseudacorus* (yellow iris), *Lytsal* = *Lythrum salicaria* (purple loosestrife), *Micvim* = *Microstegium vimineum* (stiltgrass), *Myrspi* = *Myriophyllum spicatum* (Eurasian watermilfoil), *Phaaru* = *Phalaris arundinacea* (reed canary grass), *Phr* = *Phragmites* (common reed), *Rosmul* = *Rosa multiflora* (multiflora rose), *Tranat* = *Trapa natans* (water-chestnut), *Typha* (cattail). Where two weeds are shown in a table cell they were tied for C. Where only one weed is shown in a table row it was the single major weed species. Rec = Recommendations for management of the nonnative weed(s): N = do nothing, M = monitor, C = contain, K = create space by removing part or all of the weed(s) (see below for more information).

| **Rare species** | **Rare C** | **Weed C1** | **Weed D1** | **Weed C2** | **Weed D2** | **Rec.** |
|---|---|---|---|---|---|---|
| *Bidens bidentoides* – Tivoli South | 12.0 | 20.0 *Amofru* | 4.0 | 18.0 *Micvim* | 4.0 | M |
| *Bidens bidentoides* – Kingston | 10.0 | 26.0 *Typha* | 5.0 | 24.0 *Fal* | 4.0 | M or K |
| *Bidens laevis* – Tivoli South | 12.0 | 20.0 *Amofru* | 4.0 | 18.0 *Micvim* | 4.0 | M |
| *Bidens laevis* – Fishkill Creek | 10.0 | 21.5 *Typha* | 4.5 | 19.0 *Acorus* | 5.0 | M |
| *Bolboschoenus novae-angliae* – Con's Hook | 14.0 | 26.0 *Phr* | 5.0 | 23.0 *Typha* | 5.0 | M or C |
| *Bolboschoenus novae-angliae* – Manitou | 12.0 | 25.0 *Typha* | 5.0 | 23.0 *Lytsal* | 5.0 | Verify identity; M |
| *Bolboschoenus novae-angliae* – Iona | 15.0 | 21.0 *Typha, Phr* | 5.0 | 16.0 *Lytsal* | 5.0 | K |
| *Bolboschoenus novae-angliae* – Haverstraw | 11.0 | 25.0 *Phr* | 4.0 | 21.0 *Acorus, Iripse* | 5.0 | M or K |
| *Bolboschoenus novae-angliae* - Croton | 13.0 | 24.5 *Phr* | 4.5 | 16.5 *Typha* | 4.5 | K |
| *Bolboschoenus novae-angliae* – Piermont | 10.0 | 26.0 *Phr* | 5.0 | - | - | Verify identity; C |
| *Cardamine longii* – Vanderburg | 7.0 | 23.0 *Acorus, Typha* | 5.0 | 22.0 *Lytsal* | 5.0 | M or K |
| *Cyperus flavescens* – Iona | 11.0 | 26.0 *Typha* | 5.0 | - | - | M or K |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Heteranthera reniformis* – Saugerties | 3.0 | 19.0 *Iripse* | 4.0 | 15.5 *Acorus* | 4.5 | M or K |
| *Heteranthera reniformis* – Kingston | 9.0 | 25.0 *Phr* | 4.0 | 22.0 *Typha* | 4.0 | M or K |
| *Heteranthera reniformis* – Vanderburg | 8.0 | 21.0 *Typha* | 4.0 | 19.5 *Lytsal* | 3.5 | M |
| *Lilaeopsis chinensis* – Croton | 8.0 | 26.0 *Phr* | 5.0 | 17.0 *Myrspi* | 5.0 | M |
| *Lilaeopsis chinensis* – Piermont | 12.0 | 24.5 *Phr* | 4.5 | - | - | M |
| *Limosella australis* – Croton | 10.0 | 24.5 *Phr* | 4.5 | 18.0 *Myrspi* | 5.0 | M |
| *Limosella australis* – Con's Hook (North) | 10.0 | 20.5 *Amofru, Phr* | 3.5 | - | - | M |
| *Limosella australis* – Con's Hook (South) | 11.0 | 23.0 *Typha* | 4.0 | 21.0 *Amofru* | 4.0 | M |
| *Najas guadalupensis muenscheri* – Tivoli | 7.0 | 18.0 *Myrspi* | 5.0 | 17.0 *Tranat* | 5.0 | M |
| *Orontium aquaticum* – Saugerties | 11.0 | 20.5 *Iripse* | 4.5 | 17.0 *Acorus* | 5.0 | M |
| *Orontium aquaticum* – Tivoli North | 10.0 | 23.0 *Typha* | 5.0 | 20.0 *Lytsal* | 5.0 | M or K |
| *Orontium aquaticum* – Cruger Island (Tivoli Bays) | 4.0 | 18.5 *Micvim* | 3.5 | 16.5 *Rosmul* | 2.5 | M |
| *Plantago cordata* – Saugerties | 11.0 | 19.5 *Cynlou* | 4.5 | 17.5 *Rosmul* | 4.5 | M |
| *Plantago cordata* – Tivoli North | 8.0 | 19.0 *Micvim* | 4.0 | 18.0 *Rosmul* | 4.0 | N |
| *Plantago cordata* – Kingston | 8.0 | 24.0 *Typha* | 5.0 | 17.0 *Lytsal* | 5.0 | C or K |
| *Sagittaria montevidensis* – Iona | 8.0 | 22.0 *Phr* | 4.0 | 21.0 *Myrspi* | 5.0 | M |
| *Sagittaria montevidensis spongiosa* – Saugerties | 7.0 | 18.0 *Myrspi* | 5.0 | - | - | M |
| *Sagittaria montevidensis spongiosa* – Tivoli North | 11.0 | 22.5 *Typha* | 3.5 | 18.0 *Myrspi, Tranat* | 5.0 | M |
| *Sagittaria montevidensis spongiosa* – Kingston (Stand 1) | 12.0 | 21.5 *Typha* | 3.5 | 19.5 *Lytsal* | 3.5 | M |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Sagittaria montevidensis spongiosa* – Kingston (Stand 2) | 9.0 | 21 *Tranat* | 5.0 | 20.5 *Lytsal, Typha* | 3.5 | N |
| *Sagittaria montevidensis spongiosa* – Vanderburg | 10.0 | 21.5 *Phr* | 3.5 | 19.0 *Myrspi* | 5.0 | M |
| *Sagittaria montevidensis spongiosa* – Croton | 7.0 | 24.5 *Phr* | 4.5 | 18.0 *Myrspi* | 5.0 | M |
| *Sagittaria subulata* – Saugerties | 7.0 | 14.0 *Myrspi* | 4.0 | - | - | M |
| *Sagittaria subulata* – Tivoli North | 11.0 | 22.5 *Typha* | 3.5 | 18.0 *Myrspi, Tranat* | 5.0 | M |
| *Sagittaria subulata* – Vanderburg | 10.0 | 21.5 *Phr* | 3.5 | 19.0 *Myrspi* | 5.0 | M |
| *Sagittaria subulata* – Constitution | 6.0 | 22.5 *Typha* | 3.5 | 18.5 *Phaaru* | 3.5 | M |
| *Sagittaria subulata* – Croton (Southwest) | 3.0 | 22.5 *Phr* | 4.5 | 16.0 *Myrspi* | 5.0 | M or K |
| *Sagittaria subulata* – Croton (Northeast) | 9.0 | 24.5 *Phr* | 4.5 | 18.0 *Myrspi* | 5.0 | M |
| *Spartina cynosuroides* – Haverstraw | 9.0 | 26.0 *Phr* | 5.0 | 21.5 *Amofru* | 4.5 | M |
| *Spartina cynosuroides* – Piermont | 14.0 | 25.5 *Phr* | 4.5 | - | - | C |
| *Symphyotrichum subulatum* – Iona | 14.0 | 26.0 *Typha* | 5.0 | - | - | M or K |
| *Symphyotrichum subulatum* – Haverstraw (North Stand) | 8.0 | 26.0 *Phr* | 5.0 | 21.5 *Amofru* | 4.5 | M or K |
| *Symphyotrichum subulatum* – Haverstraw (South Stand) | 10.0 | 25.0 *Phr* | 4.0 | 21.0 *Acorus, Iripse* | 5.0 | M or K |

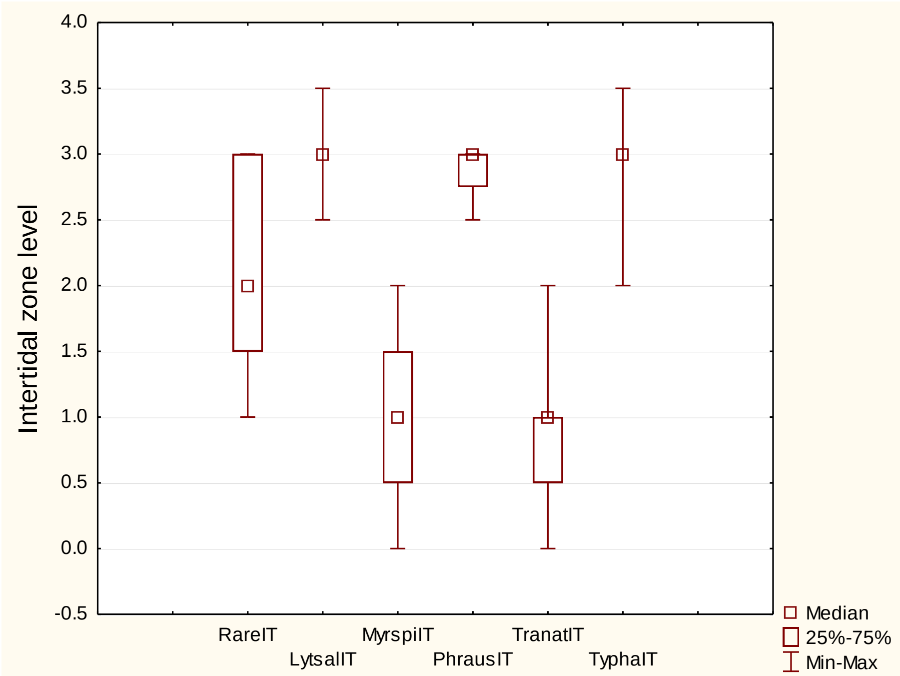


Figure 6. Intertidal zone levels of rare native plant stands (left-most box) and five of the potentially most competitive weeds (other five boxes). Rare = rare species, Lytsal = purple loosestrife, Myrspi = Eurasian watermilfoil, Phraus = common reed, Tranat = water-chestnut, Typha = cattail. The bulk of the intertidal level values for the rare species fall above Eurasian watermilfoil and water-chestnut, and below purple loosestrife, common reed, and cattail. Many other nonnative weeds also occur either in the upper intertidal zone with minor extensions into the middle intertidal zone, or in the subtidal zone with minor extensions up into the lower intertidal zone. These "extensions" (not always physical vegetative spread) tend to be smaller and probably weaker competitors than the weed at its ideal intertidal level.

The three probably most competitive nonnative weeds were generally longer than the associated rare native plants (Fig. 5). Greater length generally indicates greater vigor and biomass, and may confer a competitive advantage. Common reed and cattail density ratings were greater than purple loosestrife and rare native plant density ratings (Fig. 3). Any pattern in stand area is not obvious (Fig. 7).

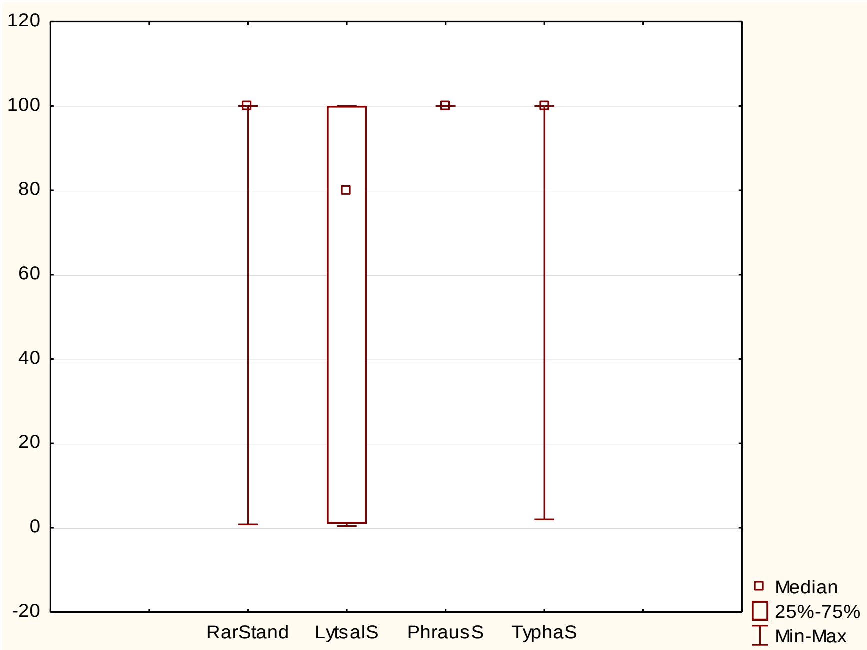


Figure 7. Stand areas for rare native plants, purple loosestrife, common reed, and cattail (left to right). Stand area was truncated at 100 $m^2$.

Figure 8 and the positive Spearman correlation of purple loosestrife competitiveness index and rare species stand area are puzzling. Possibly truncating stand area has distorted this relationship. However, the relationships of purple loosestrife to native plants can be complex. Farnsworth and Ellis (2001) found interpretation of relationships of purple loosestrife to other plants at five Connecticut (nontidal) wet meadows depended on the metrics used, but concluded that loosestrife did not seem to adversely affect density or diversity of other plants. Treberg and Husband (1999), along an Ontario river, found in 2 x 2 m plots that some native plants, including three bulrush species, were more likely to occur with loosestrife than without it. The loosestrife we observed during our study generally occurred in sparse to medium density stands admixed with other nonnative and native species.

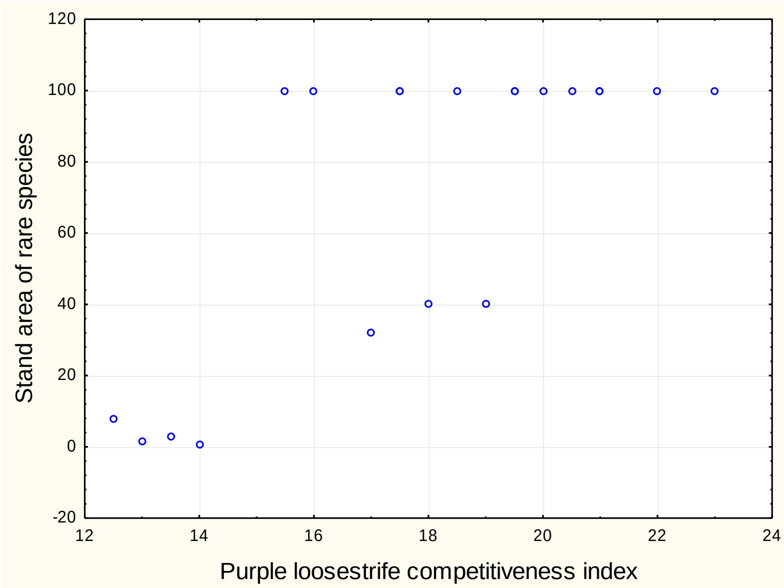


Figure 8. Area of rare native species stand vs. purple loosestrife competitiveness index (stand areas > 100 $m^2$ are truncated to 100 $m^2$). Spearman rank-order correlation: rho = 0.686, p = 0.000845.

The data in Table 6 suggest that certain rare native species are threatened to a greater or lesser degree by nonnative weeds, and also suggest certain management needs or opportunities (see Recommendations, below.)

## Discussion

Our data and observations show that nonnative weeds are potentially serious competitors of rare native plants in the Hudson River tidal wetlands. Most, if not all, of the weeds we found near rare plants were well established in the study area and thus this is predominantly not an "early detection" situation (but see below).

Given our assumptions about vigor metrics and other variables, our findings comparing nonnative weeds with rare native plants are hypothetical. These hypotheses can be tested to confirm those relationships (i.e., threats) that require management. Also our studied covered a single season with mostly one or two visits to each marsh. For many reasons, marsh vegetation may change from year to year and over longer periods. Thus any important relationship (such as New England bulrush ecology) should be studied for at least several years. Even a single event, like the deposition of sediment that seems to have occurred with the Hurricane Sandy surge in fall 2012, or a shift in beaver activity, can cause a notable local change in the vegetation and flora during a single growing season. Interspecific relationships can vary through time (Keddy 1989), and a plant that is a competitor one year could be neutral or facilitative at another time.

Would there be more or larger stands of some of the rare species if the extensive stands of cattail and common reed were absent? Probably, in some cases, yes. However, these robust dominants with their large amounts of underground biomass play an important role in sediment accretion and stabilization, and may be protecting habitat for smaller plants as well as competing with them. Managing a marsh needs to be a tradeoff between habitat for native species (or "communities"), especially those of conservation concern, and the non-habitat ecosystem services provided by robust dominants such as common reed, cattail, and purple loosestrife (see Kiviat [2013] regarding ecosystem services of reed stands). Planning management is an optimization process that considers this tradeoff as well as the goals of management, the characteristics of a particular site, the available management techniques, and other factors (see Kiviat 2010, 2013). With regard to the marshes we studied, management that best serves long-term conservation of biodiversity and other ecosystem services may require different management techniques in different portions of a site. This is complex, of course, because of diverse services (goals) and species, limited information, and the semi-predictable effects of sea level rise.

*Elevation gradient*

Our data suggest that rare native plants are competing with the community biomass of the other nonnative and native plants established in the habitat. In Tivoli North Bay, plant species stature, species richness, and aboveground biomass, as well as loose and attached litter mass and soil organic matter, increased from low to high along the elevation gradient (Kiviat and Beecher 1991). This seems to be a general feature of the fresh-tidal and brackish marshes of the Hudson River (Kiviat et al. 2006). Cattail and common reed are important components of the greater stature and biomass of the upper intertidal (and sometimes low supratidal) vegetation. These taxa have high competitiveness indices in our data (Table 5), and seem to be major competitors of rare native species. Cattail, common reed, and purple loosestrife have often been considered strong competitors and dominants in other studies of marshes (e.g., Chambers et al. 1999, Farnsworth and Meyerson 1999, Woo and Zedler 2002, Silliman and Bertness 2004, Trebitz and Taylor 2007, McGlynn 2009, Hood 2013).

*Invasibility*

Invasiveness is a property of a species and invasibility is a property of the recipient environment; both are factors in the ecology of most if not all plant invasions. Freshwater tidal marshes seem to be less invasible than some habitats (Kiviat 2009), but plant invasions do occur and a few are prominent. What makes fresh and brackish tidal wetlands invasible in the Hudson River? We should look for underlying factors (stressors) that are adverse to native species or favorable for nonnative weeds. Among such potential factors are nutrient loading, hydrological changes (including sea level rise), salinity changes, and physical alterations of the habitat (Chambers et al. 1999, Farnsworth and Meyerson 1999, Bart and Hartman 2000, Meyerson et al. 2000, Woo and Zedler 2002, Baldwin 2004, Konisky and Burdick 2004, Silliman and Bertness 2004, King et al. 2007), as well as natural disturbances (e.g., Connors et al. 2000, Minchinton 2002). The study marshes have experienced all these stressors. Nitrogen loading is high in the Hudson River (Caraco et al. 1998). Most, if not all, of the marshes have been altered, for example for salt hay management (Piermont Marsh), agriculture (Constitution Marsh), railroads (most sites), and roads (Tivoli Bays).

The Hudson River estuary with its component tidal wetlands is a very open system. Tidal circulation, ice, wind, animal activities, and human activities readily move plant propagules within and among wetlands. Seeds and fragments are both involved, and, for example, high tides probably move floating propagules into marshes and leave them stranded where germination and establishment can occur. Propagule pressure is an important component of the invasion process (e.g., Lockwood et al. 2005). Presumably it is easier for propagules to arrive at a site (or at a stand of a rare native species) in the Hudson River tidal marshes than in a small lake or another semi-isolated habitat. In addition to nutrient loading, etc., the ready dispersal of propagules from a large area (watershed, etc.) is likely to facilitate the establishment and spread of nonnative weeds (as well as native species).

*Taxonomic uncertainties*

There are uncertainties associated with a few of the species we studied (Table 7). For the purpose of this study, we accepted Long's bittercress as a good species (see Carlsen et al. 2009:225). We rejected *Bidens* occurrences at Tivoli North Bay and Vanderburg Cove in which the plants were closer to *B. cernua* (a common species) than to *B. laevis*, and accepted *B. laevis* occurrences at Tivoli South Bay and Fishkill Creek. Strother and Weedon (2006) opined that *cernua* and *laevis* might represent extremes of a single species because intermediates are common. An alternate hypothesis is that there is a hybrid swarm of the two species. We considered leafy bulrushes from Manitou Marsh south to Piermont Marsh to be New England bulrush, although the Manitou and Piermont stands were vegetative and could have been, respectively, *Bolboschoenus fluviatilis* and *B. robustus*. These stands should be checked in future years for inflorescences to confirm the identifications.

*Acorus* and *Typha*, whatever their origins, are taxa that often grow in dense, tall, extensive stands and almost certainly compete with some of the rare plants. We are not sure these are nonnative species, but they are at least sometimes invasive.

*Additional invasive plants*

Undoubtedly there are nonnative weeds that we did not sample in this study but that will colonize the Hudson River tidal wetlands and potentially threaten rare plants in the future. The railroads, the shorelines, and the river itself, are dispersal corridors for many plants, and other species may be dispersed by birds that follow the river in migration. Predicting new nonnative colonizers is beyond our scope, but two taxa should be noted. Japanese knotweed (*Fallopia japonica = Polygonum cuspidatum* and its hybrids) is established at a number of supratidal locations on the Hudson River including Tivoli Bays, Kingston Point, and Piermont Marsh. Although this is not a true wetland species it can tolerate flooding in habitats that have reasonable drainage. Knotweed potentially propagates by fragments as well as seeds. It may be able to colonize portions of the wetlands and at least occasionally compete with rare native plants in the upper intertidal or low supratidal zones; it should be monitored.

Table 7. Taxonomic problems and uncertainties of rare native and weedy nonnative plants sampled.

| **Species** | **Problem** | **Reference** |
|---|---|---|
| Rare native species | | |
| *Bidens laevis*, smooth bur-marigold | Some populations intermediate between *B. laevis* and *B. cernua* | Strother & Weedon 2006; R. Naczi & D. Werier, pers. comms. |
| *Bolboschoenus novae-angliae*, New England bulrush | Some populations of leafy bulrush(es) vegetative only and not identifiable to species | R. Naczi, pers. comm. |
| *Cardamine longii*, Long's bittercress | Taxon not universally accepted as distinct from *C. pennsylvanica* | Carlsen et al. 2009 |
| | | |
| Nonnative weeds | | |
| *Acorus*, sweetflag | Disagreement concerning whether there is a single circumboreal species or separate Eurasian and American species | Thompson no date |
| *Typha*, cattail | *T. angustifolia* & *T.* × *glauca* both present, sometimes in mixed stands; debate regarding native or European origin of *angustifolia* | Pederson et al. 2005, Ciotir et al. 2013 |

Mile-a-minute (*Persicaria perfoliata*) did not occur near any of the rare native plants we sampled. However, there was a small infestation (probably several square meters) on the natural levee on the south side of Con's Hook Marsh. Because of the propensity to densely overgrow other plants, and the apparent ability to tolerate drier wetland soils, mile-a-minute may be a threat to New England bulrush at Con's Hook. A better understanding of the potential habitat niche of mile-a-minute in the study area is needed.

*Invasive animals*

There are many nonnative species of animals in the Hudson River wetlands, and there seems to be little knowledge of them or interest in their interactions with rare plants. We will mention a few species of obvious interest.

The emerald ash borer (*Agrilus planipennis*) has been reported to kill 99% of the ashes (*Fraxinus* spp.) that it infests in 1-4 years (Poland and McCullough 2006, Poland and Herms 2014). There is a substantial infestation of this beetle in and near the Tivoli Bays, including the Cruger Island Neck tidal swamp between North Bay and South Bay. It is likely that many ashes will die in the tidal swamp in the next 5-10 years; beavers and possibly other factors have already reduced the ash - red maple tree canopy in that swamp. Further opening of the canopy might be favorable for some of the bryophytes, vascular herbs, and shrubs, although increased insolation might be unfavorable for some shade-associated species. We do not know how this will affect state-rare plants such as swamp lousewort (*Pedicularis lanceolata*) and kidney-leaved mud-plantain, or regionally-rare species such as lesser purple-fringed orchid (*Platanthera psycodes*). The tidal swamp is a hotspot for rare bryophytes (Leonardi 1991). We do not know the abundance of ashes at other tidal wetlands in the present study area where they mostly occur in small groves if at all.

Mitten crab (*Eriocheir sinensis*) is a moderately large crab (to 100 mm carapace width) that lives in fresh water and spawns in saline water. Mitten crabs are reported to burrow in stream banks and at high densities cause erosion or collapse of banks (ANS Task Force 2005). Although the mitten crab has been well documented in the Saw Kill (tributary of Tivoli Bays) and a few have been found in the estuary (Schmidt et al. 2009), no burrowing has been observed in tidal creek banks in the marshes (R. Schmidt, pers. comm.).

Common carp (*Cyprinus carpio*) has been in the Hudson River since the 1830s (Mills et al. 1997) and is common now. Hudson River carp reach almost 1 m total length (E. Kiviat, pers. obs.). The species is known to uproot and eat submergent plants and reduce submergent plant biomass (Shin-ichiro et al. 2009, Kloskowski 2011). However, the diet of adults has not been studied in the Hudson. Carp forage in areas of Tivoli North Bay where Hudson River water-nymph and the dwarf *Sagittaria* spp. occur, but we do not know if carp eat or uproot those or other rare plants. Carp have been observed grazing on common reed rhizomes and culm bases in Kearny Marsh West, Hudson County, New Jersey (Kiviat 2013).

The mute swan (*Cygnus olor*) is considered nonnative and its population on and near the Hudson River has increased greatly over the past three decades. Several studies of mute swan food habits indicated that submergents (also called "submerged aquatic vegetation" or SAV) were the staple diet (e.g., Bailey et al. 2008). *Najas flexilis* was grazed in Ontario (Bailey et al. 2008), thus there is the potential for grazing on Muenscher's water-nymph in the Hudson River. Bailey et al. also found feeding on wild-rice (*Zizania*) and the tubers of *Sagittaria*, suggesting the possibility of damage to other emergent species. We have not observed tuber production by *S. subulata* or *S. montevidensis* ssp. *spongiosa*, and do not know if swans would consume the entire small plants. A statewide mute swan control program has been proposed by the DEC; it is unclear to what degree the plan will be implemented and how much it might affect mute swan activity on the Hudson River.

The nutria (*Myocastor coypus*) is well established in Maryland, there are a few records from Delaware Bay, and one was collected in Orange County, New York, ca 20 km west of the Hudson River (Fuller 2015). Extensive damage to tidal marsh soils and vegetation has been documented in areas of the U.S. where nutria are well established (Harris and Webert 1962, Holm et al. 2011, Witmer et al. 2012). This species may well colonize the Hudson River eventually, but we are unable to say whether nutria will tolerate cold winters, and whether they will cause harm to rare plants.

Feral swine are established in parts of New York and the DEC is implementing an eradication program. As yet, there has been little evidence of feral swine in the Hudson Valley and none in the Hudson River tidal wetlands as far as we know. Feral swine damage to wetland soils and vegetation has been studied in Florida (Thomas et al. 2013, Boughton and Boughton 2014) and would be expected in New York. Feral swine can also diversify the habitat for small plants (Arrington et al. 1999). Without evidence to the contrary, however, it is best to consider feral swine a threat to rare plants (and animals) in tidal wetlands.

We note that native Canada goose, white-tailed deer, beaver, and muskrat are well documented threats to wetland plants under certain conditions. Possibly snapping turtle should be added to this list. Goldenclub in the Hudson River, for example, is undergoing a considerable amount of herbivory by medium to large vertebrates (J. Les and E. Kiviat, in press). However, native animals are beyond the scope of the present study.

## Recommendations

### *Management*

In Table 6 we indicate several general management options, namely, do nothing, monitor, contain the weed(s), or open up space in the weed stand(s). More specific recommendations follow.

The dwarf arrowheads (spongy arrowhead and strap-leaved arrowhead), the occurrences of mudwort at Con's Hook and the northeastern stand at Croton, and kidney-leaved mud-plantain at Vanderburg Cove and Kingston grow in the lower and middle intertidal zone where they are beyond the reach of most nonnative weeds due to elevation differences. Common reed at Saugerties and Con's Hook showed evidence of vegetative extension downslope to the edges of the beds of these dwarf mudflat species but the reed growth was either dead or weak. Inasmuch as extensive water-chestnut and Eurasian watermilfoil are often located just below the dwarf arrowheads, we can imagine a scenario in which a storm deposits a large amount of water-chestnut or watermilfoil biomass on top of the arrowheads and smothers them. The probability or permanence of such an event are unclear.

On the other hand, lilaeopsis and the southwestern stand of strap-leaved arrowhead at Croton, and lilaeopsis at Piermont, are associated with the outer (deep) edge of common reed stands where the dwarf species form patches extending about 0.5 m inside and outside the reed edges. In these cases the rare plants seem to be taking advantage of eroding peat edges (micro-scarps) partly stabilized by reed rhizomes. If the reeds were less dense or absent from the peat rims, the dwarf rare plants might be more vigorous. However, the reeds are probably protecting this eroding habitat and may actually be facilitating the rare plants. These relationships bear monitoring and research.

The one occurrence of Long's bittercress we found was very sparse in the interior of mixed tall vegetation in the upper intertidal – supratidal zone at Vanderburg Cove. The bittercress was vegetative (in early fall) but otherwise seemed healthy. We do not know if bittercress would do better in the open, such as at the bank of a tidal creek where it grows in some of the other sites upriver of our study area. Although the competition for light and space would seem unfavorable to this small plant, there seems to be little information on its ecology and it might be shade-tolerant. The Vanderburg Cove locality might lend itself to experimental thinning of the tall vegetation overstory to see if Long's bittercress is released from competition.

Yellow flatsedge and saltmarsh aster at Iona Island were abundant in a small area where common reed was recently treated with herbicide. Saltmarsh aster seems to be an opportunistic species based on our 2015 observations in brackish tidal marshes of the New Jersey Meadowlands, but we have no other experience with yellow flatsedge. Yellow flatsedge was considered a noxious weed in indigenous cropping in an area of Oaxaca, México (Blanckaert et al. 2007) where it was tolerant of herbicide treatment and mechanical damage. In an oligohaline coastal marsh of Louisiana, yellow flatsedge was favored by vertebrate (nutria, etc.) herbivory and disfavored by fencing against herbivory (i.e., it grew better where exposed to nutria than where nutria were excluded; Taylor et al. 1994). Yellow flatsedge established from translocated marsh organic matter in a created wetland in Florida (Shuey and Swanson 1979). These references, although from tropical and subtropical environments, suggest yellow flatsedge is also an opportunistic species tolerant of disturbance. Yellow flatsedge and saltmarsh aster should be looked for in brackish marshes disturbed by natural events and chemical or non-chemical management treatments. At Iona, they should be monitored or the bordering cattail stands contained or cut back.

New England bulrush presents a more challenging management situation. Although this species is large and may be able to resist weed competition better than smaller native species, the Hudson River stands were all bordered to a greater or lesser degree by cattail or common reed. We sampled six stands of the bulrush, at Piermont, Haverstraw, Croton, Con's Hook, Iona, and Manitou (bulrush stands at Croton and Manitou were vegetative and have not yet been confirmed as this species). All six occurrences were associated with common reed or cattail stands to a variable degree. The bulrush at Iona is in a large area recently treated with herbicide to kill common reed (the bulrush was marked and avoided during treatment; E. McGowan, pers. comm.). Very small (probably $< 1\ m^2$) patches of reed and a larger patch of cattail border portions of the bulrush stand. The reed can be hand-pulled repeatedly to kill it, and the bulrush-cattail border can be monitored.

At Con's Hook, there are at least four stands of New England bulrush, and the one we sampled was large and fruiting heavily. Common reed bordered the bulrush on three sides (separated by rivulets on two) with a large tidal creek on the fourth side. This site should be monitored to determine if the bulrush is resisting reed competition; it might be necessary eventually to contain or cut back the reed stands. Con's Hook might serve as a seed source for reestablishment of New England bulrush elsewhere. The bulrush stand at Manitou was vegetative and needs species verification. The stand is well mixed with narrow-leaved and hybrid cattails and purple loosestrife, but except for a small area near the railroad the bulrush seems vigorous and unaffected by herbivores (we saw muskrat and insect damage in the one area). Possibly bulrush is resisting cattail competition at this site, and the nearest common reed is > 50 m away.

The bulrush stand at Croton is small and surrounded by common reed on three sides. This occurrence should be monitored and possibly the reeds cut back. (Reed or cattail stands can be contained by frequent cutting at the edge, which sometimes takes several years, and one or two cuts is usually insufficient.) The stand we sampled at Piermont, along the western border of the marsh, is long and narrow with upland forest on one side and a tidal creek opposite. The narrow ends of the stand are bordered by common reed stands. Insect damage (stem borers causing the culm to bend or break about halfway up) was prevalent in this stand. We recommend that the reed stands be contained at the small contact zones between reed and bulrush, unless it is determined that this stand is inviable because of insect damage or other factors. Possibly removal of a few overhanging tree branches would give the bulrush more sunlight.

The Hudson River water-nymph at Tivoli is in the lower intertidal zone with dwarf arrowheads among and above it. Water-chestnut and Eurasian watermilfoil are on the deeper edge of the stand but are not dense. The water-nymph will probably hold its own but should be monitored.

The heart-leaved plantain stand at Tivoli is very small and has declined severely during the past 40 years (E. Kiviat pers. obs.). Although it is not directly threatened by weeds, we recommend no management as this stand is probably not viable. The plantain at Saugerties, however, is extensive and vigorous with many large fruiting plants as well as many immature plants. It does not seem threatened by weeds although several species occur supratidally above the plantain. We recommend monitoring. At the Kingston plantain stand, we recommend containing or cutting back the neighboring weeds.

Tall cordgrass, a regionally-rare species in the Hudson River, occurs in small patches at Piermont and Haverstraw. We recommend monitoring.

Close proximity of rare species and weeds requires precise techniques to manage weeds without lethal or sublethal effects on rare species. It appears that very little monitoring of such nontarget effects has been conducted in concert with management of invasive plants such as reed and cattail. Although advocates for herbicide treatment of invasive plants often state that there are no negative effects on nearby native plants, in some cases there may be sublethal effects that reduce fitness of rare native species even a year or more after exposure to herbicide or in ways that are not readily visible.

*Taxonomic issues*

Without precise species identifications, management can not be effective. Molecular markers should be developed to allow accurate identification of vegetative leafy bulrushes (*Bolboschoenus* spp.). Molecular work is also needed on the bur-marigolds *Bidens laevis* and *B. cernua* to determine if these are endpoints of a single variable species, or if there is a hybrid swarm. As far as plant conservation is concerned, it is more urgent to understand effects of cattail and sweetflag upon rare species rather than to worry about the origins of these two taxa.

Hudson River water-nymph is treated here as *Najas guadalupensis* var. *muenscheri* following National Plant Data Team (2015), although Weldy et al. (2015) called this taxon *Najas muenscheri*. It has recently been determined by molecular methods that Hudson River water-nymph is a hybrid (Les et al. 2015). Whether this is an ancient or a recent hybridization, and the implications for the conservation value of this taxon, are unclear.

*Sea level rise*

During the past 40 years, sea level has risen 3.8 mm per year in the New York City region (Sallenger et al. 2012). The Hudson River estuary is presumably experiencing this rise inasmuch as the surface of the Hudson is continuous with the ocean in the New York Bight. The rate of sea level rise is accelerating. Limited data on sediment accretion (elevation building) rates in the Hudson River marshes bracket the current rate of sea level rise widely (Kiviat et al. 2006). If eventually the upper marsh belts are reduced modestly in elevation, it is possible that the robust invasive plants will be weakened and smaller species favored to some extent. Eventually the upper marsh could be lost completely, of course, which would be unfavorable to many species.

The lower and middle intertidal zone, dwarf mudflat plants (mudwort, lilaeopsis, the arrowheads) may be forced to shift their elevational ranges upward across the gently sloping gradient. This may eventually put them up against the natural bank levees that occur bordering some marsh pools and creeks, such as the northern bridge pool (Pool II) in Tivoli North Bay. If these levees withstand sea level rise for a period, there might be an elevational "squeeze" between Mean Low Water and its weeds (water-chestnut, Eurasian watermilfoil) and the weeds of the upper intertidal zone (common reed, cattail). There may be other sea level rise effects that we can not anticipate.

*Management*

Hudson River tidal marshes are probably invasible by robust emergent nonnative weeds because of high nutrient levels and physical alterations. Given these underlaying factors, it makes more sense to target specific weed – rare native plant interations for management rather than attempting to control weeds on a large scale. Therefore we have focused on indicators of weed threat to rare natives, and the potential for managing vegetation to conserve populations of the rare species. Baldwin (2004) cautioned that restoration of freshwater tidal marshes in urban environments should aim for a diverse novel vegetation rather than a mostly-native vegetation that is more likely to occur in a rural environment. Of course, invasibility factors may interfere with successful management of rare native plants.

Our results indicate a few rare native species and nonnative weeds for which the hypotheses generated by our study require in-depth study before evidence-based management can be formulated. This is especially a concern if herbicide is to be used as a management technique, inasmuch as it may harm the rare species we are trying to protect as well as other nontarget plants and animals. Recent herbicide treatment of common reed at Iona Island Marsh (Ed McGowan, pers. comm.) has evidently opened space for New England bulrush, saltmarsh aster, and yellow flatsedge that either established from the seedbank or were present but suppressed beneath reed stands. Herbicide treatment might seem promising for the conservation of these, and possibly other rare native, species; however, there has been no direct study of lethal or sublethal effects of herbicide (in this case, a glyphosate-based herbicide) on nontarget plants including rare natives, or on animals.

It is hard to find plants, especially small ones or ones that occur sparsely, in extensive tidal marshes with tall dominant species. Field biologists know all too well that it can take years and many surveys to find cryptic species. The Naczi-Werier team, and the Natural Heritage Program, have done a lot of good field work without which we would not have been able to conduct our study. But much more field work is needed to find additional occurrences, or relocate historically documented occurrences, of rare native plants. Many of the species we studied should be monitored in the long term, by means of permanent plots or other techniques, because these plants have conservation value and are indicators of wetland and landscape conditions as well as being scientifically interesting research subjects. Moreover, monitoring would help detect environmental problems before they cause widespread harm to wetland systems. Research is also needed to determine how robust nonnative weeds, especially common reed and cattail, are competing with (or in some cases facilitating) rare native species, and how these relationships may be managed for the long-term benefits of both rare native plant conservation and the non-habitat ecosystem services provided by the weeds (on this latter point, see Kiviat [2013] about common reed).

Ironically, some of the rare native species we studied are weeds in other countries, among them kidney-leaved mud-plantain (Hussner 2012). Research on this phenomenon could lead to important insights for management.

Native overabundant or "invasive" species deserve more attention. The example of goldenclub, which is subject to considerable damage by large grazers (Les and Kiviat in press), instructs that white-tailed deer, beaver, muskrat, and Canada goose ecology need study in the tidal marshes where all except the muskrat were rare until ca 25 years ago. Similarly, the cattails, whatever their geographic origin, can probably stress certain rare native plants. Plant conservation requires better understanding of all factors that impinge on a species of concern.

Invasive nonnative plants are indeed a concern for conservation of rare native plants, especially where the nonnative species develop extensive, dense, tall stands, and where they grow at the same tide levels as rare natives. Our competitiveness analysis indicates that common reed does seem a threat to some of the rare natives, New England bulrush among them. There is a pressing need to develop non-chemical, non-biocontrol techniques for managing weeds in close proximity to, or among, rare native species. All biologists and managers who work in the Hudson River wetlands, or other systems, can collaborate on these efforts. There are some promising examples, including prescribed goat grazing (Silliman et al. 2015). Ongoing research in the North Central states endeavors to manipulate the microbial community to give native plants a competitive advantage over nonnativer common reed (Kowalski 2015).

Invasive species that are not yet affecting plant diversity or rare native plants in the tidal wetlands need attention as "early detection" species or "arriving" species. Prominently among those are Japanese knotweed and mile-a-minute vine. Where mile-a-minute is becoming established (Con's Hook Marsh is the best example, although mile-a-minute is not yet threatening anything rare there as far as we know), local release of the biocontrol weevil (Lake et al. 2011) should be considered, with hand-pulling of mile-a-minute as an alternative. Because the mile-a-minute biocontrol program is well underway in New Jersey and New York, and the weevils spread on their own, introducing weevils to Con's Hook would probably not be an additional threat to other Polygonaceae. Girard-Cartier and Kleppel (2015) had good results with prescribed sheep grazing for control of mile-a-minute. Knotweed can be controlled by frequent cutting or stem injection of herbicide (Hartwig and Kiviat 2009). There are many other techniques available for containing, inhibiting, partially removing, or eradicating stands of invasive plants (see, e.g., Kiviat 2010).

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