Kirkwood-Cohansey Project

The Potential Impact of Simulated Water-level Reductions on Intermittent-pond Vegetation

State of New Jersey Pinelands Commission

Cover: Vegetation zones at Burnt Pond include aquatic-herbaceous areas (foreground), which are dominated by water shield (*Brasenia schreberi*), and monotypic stands of Walter's sedge (*Carex striata*). Photograph taken by Kim J. Laidig.

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ABSTRACT

Vegetation models were developed and used to predict the potential effect of simulated water-level drawdowns due to groundwater withdrawals on intermittent-pond plant communities associated with a shallow, unconfined aquifer. Five dominant vegetation communities, including aquatic- and wetland-herbaceous, *Carex striata*, *Chamaedaphne calyculata*, and *Vaccinium corymbosum* patch types, occurred at 15 study ponds. Greatest mean water depths were associated with the aquatic- and wetland-herbaceous patch types, followed by *C. striata*, *C. calyculata*, and *V. corymbosum* patch types. A single-pond model was created to relate mean vegetation cover for the five patch types to water level in 5-cm classes. Groundwater withdrawals were simulated by reducing pond-water depth by 5-cm intervals and the resulting changes in modeled vegetation were assessed. Aquatic- and wetland-herbaceous patch types, which represent the open-water portion of ponds, were the most sensitive to simulated drawdowns and displayed reductions in area beginning at the smallest drawdown evaluated. *C. striata* patch area changed only slightly for drawdowns ≤10 cm, but decreased steadily in response to greater drawdowns. *C. calyculata* and *V. corymbosum* patch area increased for water-level reductions ≤15 cm and then decreased at drawdowns ≥20 cm. The area of combined pond-vegetation types, which represents the entire pond as a single vegetation community, displayed little change at the 5-cm water-level reduction but decreased steadily at reductions of ≥10 cm. These simulations, along with previous research, suggest that permanent water-level reductions due to groundwater withdrawals favor the expansion of woody species into the interior of intermittent ponds, with eventual replacement of pond vegetation by adjacent forest vegetation if extreme hydrologic modifications occur.

INTRODUCTION

Shallow depressions that support intermittent ponds occur throughout the coastal plain of southern New Jersey (Wolfe 1953, Lathrop et al. 2005). Hydrologic conditions associated with intermittent ponds in the New Jersey Pinelands are characterized by bankfull or flooded conditions in the early part of the growing season and dewatered conditions in the latter part of the growing season (Zampella and Laidig 2003). Annual and seasonal water-level variations are associated with the presence of distinct vegetation zones in Pinelands ponds (Zampella and Laidig 2003), a feature that commonly occurs in depressional wetlands elsewhere in the United States, including pondshores in the northeast (Zaremba and Lamont 1993), Carolina bays in the southeast (Tyndall et al. 1990, Sharitz 2003), and prairie potholes in the midwest (Kantrud et al. 1989, van der Valk 2005). In addition to supporting wetland-shrub and emergent- and aquatic-herbaceous vegetation communities, intermittent ponds contribute to regional biodiversity by providing habitat for unusual or rare aquatic and wetland plants (McCarthy 1987, Zaremba and Lamont 1993, Kirkman and Sharitz 1994, Schneider 1994, McHorney and Neill 2007) and breeding sites for rare amphibians (Bunnell and Zampella 1999, Zampella and Bunnell 2000). Although changes in pond vegetation have been associated with altered hydrologic regimes due to drainage, agriculture, urban development, and groundwater withdrawals (Zaremba and Lamont 1993, Sorrie 1994, Kirkman et al. 1996), the effect of altered hydrology on pond vegetation in the New Jersey Pinelands has not been examined. No attempts have been made to model potential vegetation changes in intermittent ponds in response to water-level drawdowns from groundwater withdrawals.

Hydrologic conditions in Pinelands wetlands are primarily influenced by groundwater associated with the Kirkwood-Cohansey aquifer, a shallow unconfined system with unconsolidated sediments that underlies most of the Pinelands region (Rhodehamel 1979a, 1979b, Zapecza 1989). Because of the connectivity between this aquifer and wetlands of the region, groundwater withdrawals from the aquifer can potentially alter the hydrology of adjacent wetlands. In an unconfined aquifer, groundwater pumping lowers the water table within a cone of depression that extends laterally away from the well (Winter 1988), with direct impacts to wetland hydrology occurring if the cone of depression intersects the wetland. This effect was demonstrated in aquifer tests at two Pinelands locations, where groundwater pumping induced water-level declines in adjacent wetlands (Lang and Rhodehamel 1963, Charles and Nicholson in press). The direct effects of groundwater pumping in the vicinity of a Massachusetts coastal plain pond underlain with unconsolidated glacial deposits of sand and gravel included reduced year-round pond-water levels and other changes to the hydrologic regime (McHorney and Neill 2007).

This study on intermittent ponds is one component of a comprehensive project that assessed the potential hydrologic and ecological effects of groundwater withdrawals from the Kirkwood-Cohansey aquifer on various Pinelands aquatic and wetland systems (Pinelands Commission 2003). In this study, I characterized major vegetation-community types in intermittent ponds and determined what hydrologic regimes are associated with these communities. I used these results to develop and apply models to predict possible shifts in plant communities that may result from simulated water-level drawdowns due to groundwater withdrawals.

Methods

Study-site Selection

Fifteen intermittent ponds associated with the Rancocas Creek and Mullica River watersheds in the New Jersey Pinelands were selected (Figure 1). The ponds are located on state-owned lands, including Brendan Byrne State Forest, Bass River State Forest, and Greenwood Wildlife Management Area, and are associated with the Kirkwood-Cohansey aquifer system. Site-selection criteria included accessibility, the presence of an open-water center surrounded by herbaceous or shrubby vegetation, and geographic proximity to McDonalds Branch, a small Rancocas Creek tributary where concurrent hydrologic and ecological studies on the Kirkwood-Cohansey aquifer were conducted (Walker et al. 2008, Laidig et al. 2010, Walker and Storck in press, Charles and Nicholson in press). All ponds are situated within extensive upland and wetland forests, with negligible amounts of developed and agricultural lands in the vicinity.

The 15 ponds appeared to be associated with naturally occurring depressions because steeply cut banks, an indicator of human disturbance associated with excavation (Zampella and Laidig 2003), were absent. All of the ponds were discernable on digital aerial photography representing 1930 conditions (Sass 1992). Based on a survey of aerial photography from the 1979, 1986, 1991, 1995–1997, 2000, and 2002 periods, there was no evidence of significant disturbances such as timber harvesting and wildfire in the immediate vicinity of the ponds.

Hydrologic conditions

Staff gages were installed at the deepest point in each pond. Same-day, bimonthly (every two weeks), water-level measurements were collected at each gage from March through October in 2005 and 2006. Water-level measurements were collected at least three days after a significant rain event (>2.5 cm) and when hydrographs from the nearby McDonalds Branch hydrologic-benchmark station (Mast and Turk 1999) indicated baseflow conditions. To assess how closely pond-water levels were related, bimonthly water-level values for each pond were correlated with all other ponds using Spearman rank correlation.

To determine if hydrologic conditions associated with the 2005 and 2006 growing seasons differed from long-term conditions, monthly mean-discharge data for the McDonalds Branch hydrologic benchmark station and Mann-Whitney tests were used to compare study-period and long-term stream-discharge regimes. Long-term discharge data included all available growing-season values from October 1953 through October 2004. Discharge data were accessed online from the U. S. Geological Survey Surface-Water Data for USA webpage (http://waterdata.usgs.gov/nwis/sw).

Bathymetry

To obtain pond bathymetry, water depths were measured in March and April 2005 along transects established perpendicular to the long axis of each pond. This period typically coincides with maximum water depth in Pinelands ponds (Zampella and Laidig 2003). Depending on pond size, transects were established at 5- or 10-m intervals with 10 to 15 transects in each pond. Water depths were recorded along the transects at three intervals, including 1-m intervals near the pond perimeter (an area often characterized by relatively high topographic relief), 2-m intervals within relatively small vegetation patches, and 4-m intervals in relatively large vegetation patches. A staff-gage reading was recorded on the day that water-depth data were collected. The locations of water-depth collection points were recorded with

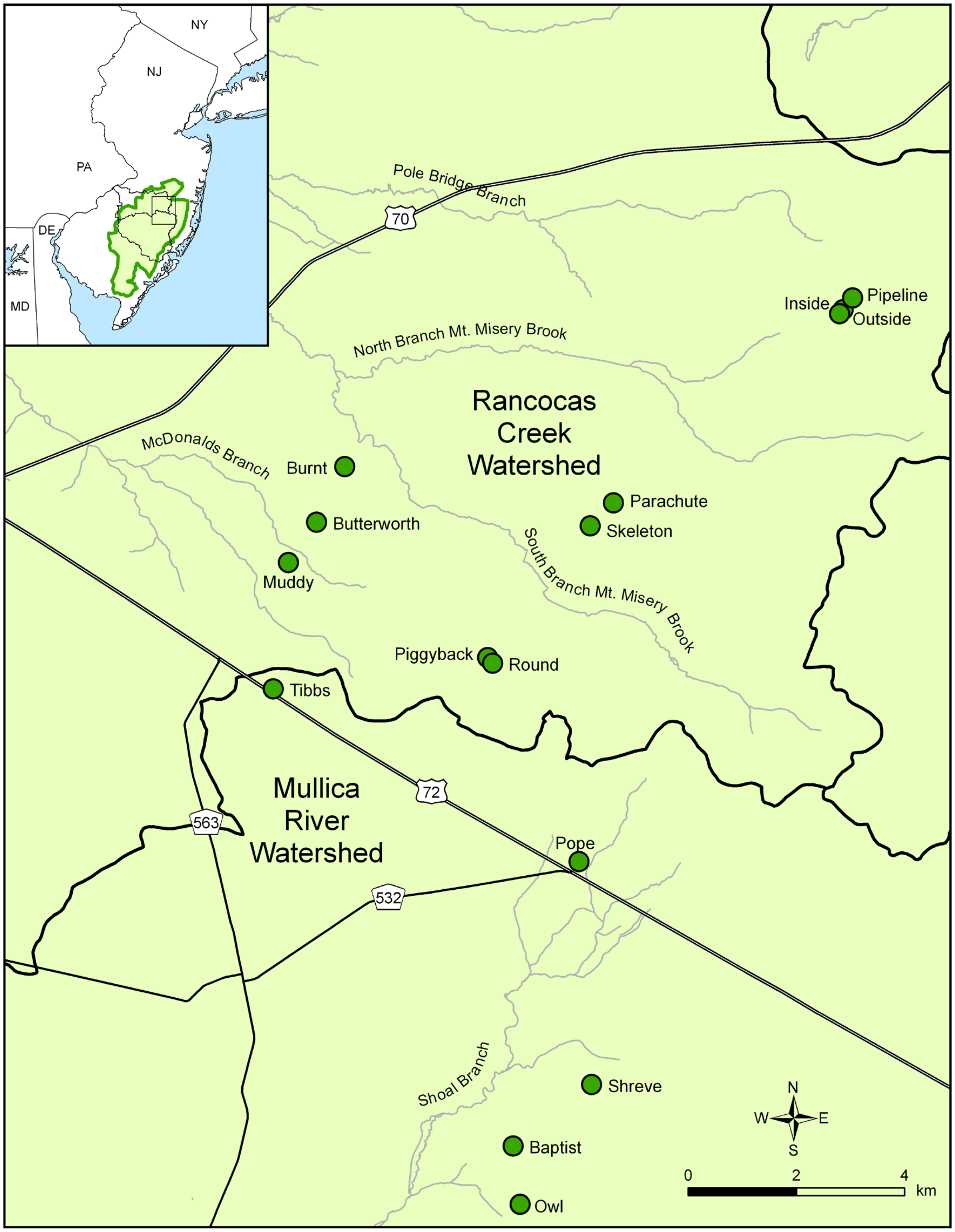

Figure 1. Location of 15 ponds in the eastern Rancocas Creek and northeastern Mullica River watersheds of the New Jersey Pinelands (shaded area, inset).

a GPS and exported to a GIS to create a water-depth data layer. Raster bathymetric maps were constructed for each pond using the water-depth data layer, ArcView software, and the inverse-distance-squared-weighted-interpolation (IDW) method set to a 1-m output grid-cell size. With the IDW method, water depths for individual grid cells were interpolated from the nearest five water-depth points within a maximum distance of 10 m.

Vegetation Composition

Patches of homogenous vegetation within

each pond were delineated in 2004 with a global positioning system (GPS) capable of submeter accuracy that recorded positions at 1-second intervals. The location of the pond perimeter, which is defined in this study as the treeline of the adjacent forest, was also recorded. In general, the treeline corresponds to the extent of surface-water area during normal high-water conditions. The geodata were exported to a geographic information system (GIS) and used to create pond-perimeter and vegetation-patch data layers.

Using a grid with one hundred cross-hair points and the point-intercept method, vascular-plant-species cover and *Sphagnum* cover were measured in July–August 2005 in 1-m^2 plots that were randomly located within the vegetation patches. The plots were revisited in October 2005, a period when all but one of the ponds had dried, and the species-cover values were modified if cover increased or if additional species were found. The number of plots established in each pond (range: 15 to 87) and patch type (range: 3 to 36) was scaled to the pond and patch-type area of each pond. The cover measurements were used to calculate mean species cover for each patch type in the ponds. New species that were found during vegetation presence-absence surveys that were conducted periodically at each of the ponds during the 2004–2006 growing seasons (March through October) were recorded merely as present. The presence of *Sphagnum* species was also recorded at each of the 15 ponds during 2005. Taxonomic nomenclature for vascular plants and *Sphagnum* was based on Gleason and Cronquist (1991) and Crum (1984), respectively. Voucher specimens representing most of the plant species encountered during the study were deposited in the Pinelands Commission herbarium.

Based on cover measurements in the 1-m^2 plots, vegetation patches with ≥10% total vascular plant cover were assigned the names of the dominant species present and patches with <10% cover were classified as mixed-herbaceous patches. Additionally, vegetation patches located in the open-water center of the ponds were combined to form wetland-herbaceous and aquatic-herbaceous patch types based on the habitat association (i.e., aquatic vs. wetland) of individual herbaceous species present in the patch. Habitat associations were based on descriptions given by Gleason and Cronquist (1991) and Godfrey and Wooten (1979, 1981). Patches were designated as aquatic-herbaceous if the combined cover of aquatic species exceeded that of wetland species, whereas patches supporting a greater relative abundance of wetland species were classified as wetland-herbaceous types. A raster vegetation-patch map with 1-m grid-cell size was constructed for each pond. ArcView software (Environmental Systems Research Institute Inc., Redlands, CA, 1999–2006) was used to create the vegetation-patch map and to calculate the area associated with each vegetation patch in the ponds.

Vegetation-patch Water Levels

Raster bathymetric maps, raster patch-type maps, and the staff-gage readings for the measurement date representing the maximum water-depth for the study period were used to calculate summary water-depth statistics for each vegetation-patch type in each pond. Mean water levels at high-water conditions associated with each of the most frequently occurring patch types were compared using Kruskal-Wallis ANOVA. Post-hoc comparisons were conducted using multiple comparisons of mean ranks (Siegel and Castellan 1988). An alpha level of 0.05 was used to identify significant results for all statistical tests.

Vegetation Patch-type Model

To assess potential water-drawdown impacts to pond vegetation and to have broad applicability to ponds in the region, a single-pond model was created. Raster bathymetry maps for each pond were broken into 5-cm water-depth classes. The proportion of area occupied by the individual patch types was calculated for each water-depth class. The patch-type proportions associated with each water-depth class were averaged across the 15 ponds and were used as probabilities to predict patch-type occurrence for each class (Auble et al. 1994). The area associated with each water-depth class was also calculated for each pond and averaged across the 15 ponds.

Drawdown Simulations

Simulated water-level drawdowns were applied to the model pond in 5-cm increments up to a maximum of 50 cm. For each of the water-level drawdown simulations, the total area of each patch type was calculated by summing the product of the patch-type probability and pond area associated with each water-depth class. The response of the most frequently occurring patch types and all pond vegetation combined into a single patch type to the various water-level drawdown scenarios were evaluated graphically. The combined pond-vegetation type was evaluated because it serves to represent the entire pond as a single vegetation community.

RESULTS

Hydrologic Conditions

Mean monthly growing-season discharge at McDonalds Branch for the study period did not differ significantly from long-term (1954 through 2004) mean monthly growing-season discharge ($p = 0.44$). This indicates that hydrologic conditions during the study period were similar to long-term conditions.

The April 11, 2005 water-level measurement date represented high-water conditions for the study period for most of the ponds (Figure 2). Maximum pond-water depths for the study period ranged from 30 to 111 cm for the 15 ponds. With the exception of a single pond in 2005 and two ponds in 2006, all ponds dried completely by the end of the growing season in both years. Bimonthly water levels were significantly ($p < 0.05$) correlated among the ponds (Table 1), indicating that the ponds exhibited similar patterns in growing-season water-level fluctuations.

Vegetation

Species inventory. A total of 68 vascular-plant taxa, including 44 herbaceous and 24 woody species, were found at the 15 ponds (Table 2). Herbaceous species that occurred at more than one-half of the ponds included *Carex striata*, *Eleocharis flavescens* var. *olivacea*, *Drosera intermedia*, *Nymphaea odorata*, *Panicum verrucosum*, *Xyris difformis*, *Utricularia fibrosa*, and *Woodwardia virginica*. Twenty-four (55%) of the herbaceous species occurred at three or fewer ponds. With the exception of *C. striata* and *U. fibrosa*, most herbaceous species were typically characterized by low abundance (Appendix 1). Total-species richness ranged from 19 to 43 at the 15 ponds. Based on a plant-classification scheme described by Zampella et al. (2006), all of the herbaceous and woody plant species encountered at the ponds are considered native to the Pinelands.

Thirteen (30%) of the herbaceous species were classified as aquatic plants (Table 2). These consisted primarily of floating-leaved, submerged, or free-floating plants that are typically associated with standing or flowing water. The remaining species were wetland plants that are typically associated with moist or wet soil of bogs, marshes, wet woods, or swamps.

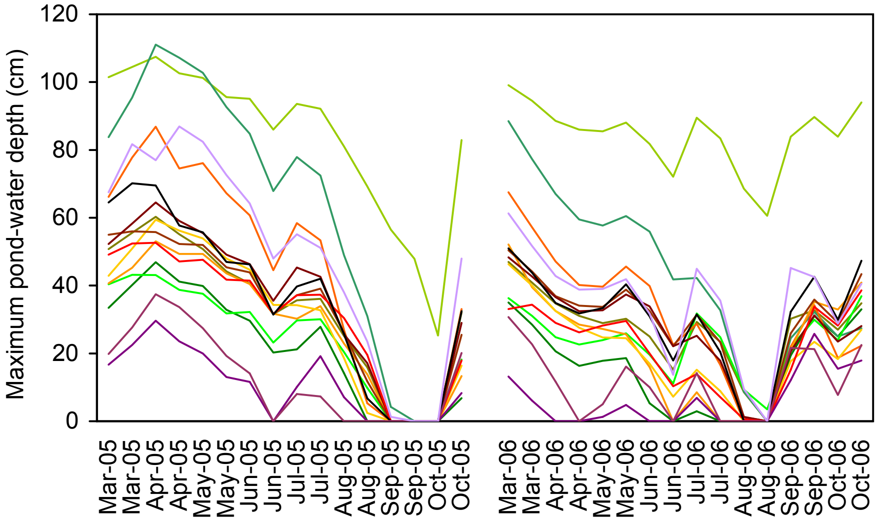

Figure 2. Growing-season hydrographs for 2005 and 2006 for 15 ponds in the New Jersey Pinelands. Hydrographs are based on bimonthly water-level measurements recorded at the deepest point in each pond.

Table 1. Spearman rank correlation matrix for growing-season (2005 and 2006) bimonthly water levels (n = 32) for 15 ponds. All correlations are significant ($p < 0.05$).

	Baptist	Burnt	Butterworth	Inside	Muddy	Outside	Owl	Parachute	Piggyback	Pipeline	Pope	Round	Shreve	Skeleton	Tibbs
Baptist	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Burnt	0.95	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Butterworth	0.94	0.97	1.00	-	-	-	-	-	-	-	-	-	-	-	-
Inside	0.79	0.89	0.88	1.00	-	-	-	-	-	-	-	-	-	-	-
Muddy	0.90	0.92	0.98	0.81	1.00	-	-	-	-	-	-	-	-	-	-
Outside	0.86	0.93	0.91	0.98	0.84	1.00	-	-	-	-	-	-	-	-	-
Owl	0.98	0.93	0.93	0.81	0.88	0.86	1.00	-	-	-	-	-	-	-	-
Parachute	0.93	0.95	0.94	0.94	0.88	0.96	0.94	1.00	-	-	-	-	-	-	-
Piggyback	0.94	0.96	0.97	0.90	0.94	0.94	0.94	0.95	1.00	-	-	-	-	-	-
Pipeline	0.88	0.94	0.92	0.97	0.86	0.99	0.88	0.96	0.96	1.00	-	-	-	-	-
Pope	0.94	0.93	0.93	0.86	0.89	0.89	0.94	0.94	0.95	0.92	1.00	-	-	-	-
Round	0.95	0.97	0.97	0.84	0.94	0.90	0.93	0.92	0.97	0.92	0.93	1.00	-	-	-
Shreve	0.87	0.80	0.79	0.56	0.80	0.64	0.81	0.70	0.76	0.67	0.80	0.83	1.00	-	-
Skeleton	0.84	0.84	0.82	0.62	0.81	0.72	0.79	0.72	0.80	0.73	0.72	0.88	0.81	1.00	-
Tibbs	0.88	0.96	0.93	0.90	0.87	0.92	0.85	0.92	0.90	0.92	0.88	0.91	0.75	0.80	1.00

Twelve species of *Sphagnum* were found at the 15 ponds, with individual ponds supporting from 1 to 8 species (Table 2, Appendix 1). *Sphagnum cuspidatum* occurred at all of the ponds. Three *Sphagnum* taxa were represented by a single occurrence.

Patch-type inventory. Twenty-five vegetation-patch types were identified at the 15 ponds (Table 3). Patches dominated by *Chamaedaphne calyculata* and *Vaccinium corymbosum*, both woody species, and *C. striata*, a persistent herbaceous perennial, were the most frequently occurring patch types. Most herbaceous-patch types associated with the open-water center of the ponds occurred infrequently. Based on the relative abundance of aquatic and wetland species, seven of these herbaceous-patch types were combined to form an aquatic-herbaceous type and nine herbaceous patches were combined to form a wetland-herbaceous type (Table 3, Appendix 2). Pond area, representing the combined area of all patch types at a pond, ranged from 0.10 to 1.28 ha (Table 3).

Based on the relatively low cover of associated vascular species measured in the 1-m^2 plots, *C. calyculata* and *C. striata* patch types could be characterized as monotypic (Appendix 2). Although no measurement plots were established in *V. corymbosum* patches due to high stem density, field observations indicated that this type could also be considered monotypic. *Sphagnum* moss was a relatively prominent component of most patch types (Appendix 2).

Vegetation-patch zonation was evident at most ponds (Figure 3). When present, *V. corymbosum* patches typically occurred near the pond perimeter, followed by *C. calyculata* and *C. striata* patches toward the pond interior. Although aquatic- and wetland-herbaceous patches occurred in the open-water pond interior, there was no consistent order of the two patch types relative to each other in the four instances where they both occurred. Outlines for many vegetation patches appeared to follow bathymetric contours at the 15 ponds (Figures 3 and 4).

Vegetation-patch Water Levels

There was an apparent gradient in mean water levels for the five most frequently occurring patch types (Figure 5). Greatest mean water depths were associated with the aquatic- and wetland-herbaceous patch types, followed by *C. striata*, *C. calyculata*, and *V. corymbosum* patch types. This overall trend, which generally corresponded with vegetation-patch zonation patterns, was also present within individual ponds. Although a gradient in patch-type water levels was evident, a Kruskal Wallis ANOVA test indicated that only aquatic- and wetland-herbaceous patch types differed significantly ($p < 0.01$) from both *C. calyculata* and *V. corymbosum* patch types.

Table 2. Herbaceous-, woody-, and *Sphagnum*-species occurrence at 15 ponds in the New Jersey Pinelands. Values refer to the percentage of 15 ponds where each species occurred. Aquatic and wetland classifications for herbaceous species are based on descriptions in Gleason and Cronquist (1981) and Godfrey and Wooten (1979, 1981).

Species	Classification	%	Species	%
Herbaceous Species:			Woody Species:	
Amphicarpum purshii	wetland	7	*Acer rubrum*	100
Brasenia schreberi	aquatic	33	*Acer rubrum* (seedling)	27
Carex striata	wetland	80	*Amelanchier canadensis*	40
Cladium mariscoides	wetland	13	*Aronia arbutifolia*	80
Cyperus dentatus	wetland	20	*Betula populifolia*	13
Decodon verticillatus	wetland	27	*Cephalanthus occidentalis*	20
Drosera filiformis	wetland	7	*Chamaecyparis thyoides*	7
Drosera intermedia	wetland	73	*Chamaedaphne calyculata*	93
Dulichium arundinaceum	wetland	33	*Clethra alnifolia*	47
Eleocharis flavescens var. *olivacea*	wetland	80	*Eubotrys racemosa*	93
Eleocharis microcarpa	wetland	40	*Gaultheria procumbens*	13
Eleocharis robbinsii	aquatic	27	*Gaylussacia baccata*	20
Eleocharis tricostata	wetland	13	*Gaylussacia dumosa*	47
Erianthus giganteus	wetland	7	*Gaylussacia frondosa*	60
Eriocaulon aquaticum	aquatic	7	*Ilex glabra*	73
Eriocaulon compressum	aquatic	20	*Kalmia angustifolia*	87
Euthamia tenuifolia	wetland	7	*Lyonia ligustrina*	20
Fimbristylis autumnalis	wetland	7	*Lyonia mariana*	67
Hypericum canadense	wetland	33	*Nyssa sylvatica*	73
Juncus militaris	aquatic	7	*Pinus rigida*	100
Juncus pelocarpus	wetland	47	*Rhododendron viscosum*	27
Nuphar variegata	aquatic	7	*Sassafras albidum*	7
Nymphaea odorata	aquatic	60	*Smilax rotundifolia*	87
Nymphoides cordata	aquatic	7	*Vaccinium corymbosum*	100
Orontium aquaticum	aquatic	13	*Vaccinium macrocarpon*	27
Panicum longifolium	wetland	7	*Sphagnum* Species:	
Panicum verrucosum	wetland	60	*Sphagnum angermanicum*	7
Panicum virgatum	wetland	13	*Sphagnum bartlettianum*	40
Panicum spretum	wetland	27	*Sphagnum cuspidatum*	100
Proserpinaca pectinata	aquatic	20	*Sphagnum flavicomans*	7
Rhexia virginica	wetland	40	*Sphagnum henryense*	13
Rhynchospora alba	wetland	27	*Sphagnum macrophyllum*	7
Rhynchospora fusca	wetland	13	*Sphagnum magellanicum*	47
Rhynchospora inundata	wetland	7	*Sphagnum palustre*	13
Scirpus cyperinus	wetland	7	*Sphagnum papillosum*	13
Scirpus subterminalis	aquatic	7	*Sphagnum pulchrum*	60
Scleria reticularis	wetland	7	*Sphagnum recurvum*	47
Triadenum virginicum	wetland	20	*Sphagnum tenerum*	13
Utricularia fibrosa	aquatic	53		
Utricularia subulata	wetland	47		
Utricularia geminiscapa	aquatic	40		
Woodwardia virginica	wetland	53		
Xyris difformis	wetland	60		
Xyris smalliana	wetland	20		

Table 3. Herbaceous- and woody-patch types at 15 ponds in the New Jersey Pinelands. Cover values are expressed as a percentage of total pond area. Pond area (ha) is given in parentheses beside pond names. Vegetation patches with >10% total vascular plant cover were assigned names based on the dominant species present. Patches with <10% cover were classified as mixed-herbaceous patches. (A) and (W) denote herbaceous-patch types located in the open-water center that were combined to form aquatic-herbaceous and wetland-herbaceous types, respectively. Refer to Appendix 2 for the species composition of individual patch types.

	Baptist (0.55)	Burnt (1.08)	Butterworth (0.64)	Inside (0.33)	Muddy (0.26)	Outside (0.18)	Owl (1.07)	Parachute (1.28)	Piggyback (0.25)	Pipeline (0.24)	Pope (0.39)	Round (0.10)	Shreve (0.85)	Skeleton (0.84)	Tibbs (0.25)
Herbaceous-patch types:															
Mixed Herbaceous (W)	-	-	29.8	14.1	-	29.8	-	52.1	30.9	-	-	-	-	-	31.4
Brasenia schreberi (A)	-	6.7	-	-	-	-	-	-	-	-	4.8	-	-	-	0.3
Carex striata	22.4	47.2	-	-	4.5	-	-	10.5	0.7	1.7	0.4	-	0.3	35.9	-
Cladium mariscoides (W)	-	-	-	-	-	-	13.8	-	-	-	-	-	-	-	-
Decodon verticillatus	-	-	1.1	-	-	-	-	-	-	-	-	-	-	-	-
Dulichium arundinacea (W)	-	-	-	-	-	-	-	-	-	11.4	-	-	-	-	-
Eleocharis flavescens (W)	-	-	-	-	-	-	-	-	-	-	-	-	-	4.8	-
Eleocharis microcarpa (W)	-	-	-	-	-	-	-	-	-	-	-	18.8	-	-	-
Eleocharis robbinsii (A)	-	2.4	-	-	-	-	67.4	-	-	-	-	-	-	-	-
Eriocaulon compressum (A)	-	0.5	-	-	-	-	1.1	-	-	-	-	-	-	-	-
Hypericum canadense (W)	-	-	-	26.0	-	9.3	-	-	-	-	-	-	-	-	-
Juncus pelocarpus (A)	-	-	-	-	-	-	3.3	-	-	-	-	-	-	-	-
Nymphaea odorata (A)	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panicum virgatum	-	-	-	-	-	-	1.0	-	-	-	-	-	6.9	-	-
Rhynchospora fusca (W)	-	-	-	-	-	-	-	-	-	-	-	-	2.9	-	-
Scirpus cyperinus (W)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4
Utricularia fibrosa (A)	-	-	17.9	-	-	-	-	-	-	39.3	84.6	61.3	-	-	-
Utricularia gemminscapa (A)	-	-	-	-	57.6	-	-	-	-	-	-	-	-	-	-
Utricularia subulata	1.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Woodwardia virginica	-	-	5.6	-	-	-	-	-	-	-	-	-	-	-	-
Xyris difformis (W)	-	-	-	-	-	-	-	-	-	-	-	-	27.7	-	-
Woody-patch types:															
Chamaedaphne calyculata	74.7	31.0	45.5	-	37.9	12.8	12.6	0.3	65.7	47.6	10.2	13.8	56.2	12.2	16.2
Ilex glabra	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinus rigida	-	0.6	0.1	1.3	-	-	-	0.7	1.7	-	-	-	1.4	1.4	-
Vaccinium corymbosum	-	11.0	-	58.7	-	48.0	0.7	36.3	1.1	-	-	6.0	4.6	45.7	50.8

Vegetation Patch-type Model

A single-pond model relating mean vegetation cover to water level in 5-cm classes was created using the five most frequently occurring patch types (Figure 6). Wetland-herbaceous patch cover generally increased, whereas *V. corymbosum* patch cover decreased with increasing water depth. Aquatic-herbaceous patch cover increased with increasing water depth up to approximately 55–60 cm and then declined with greater depths. The distribution of *C. striata* patch cover resembled a Gaussian (bell-shaped) pattern. *C. calyculata* patch cover remained relatively stable for water depths up to 20–25 cm and then decreased with increasing water depth.

Drawdown Simulations

The five dominant patch types showed varying responses to simulated reductions in water-depth (Figure 7). Aquatic- and wetland-herbaceous patch types, which represent the open-water portion of the pond, exhibited nearly identical decreases in cover that began at water-level reductions of ≥5 cm. The *C. striata* type showed very little change for reductions of ≤10 cm, but steadily decreased for reductions ≥15 cm. In contrast, *C. calyculata* and *V. corymbosum*

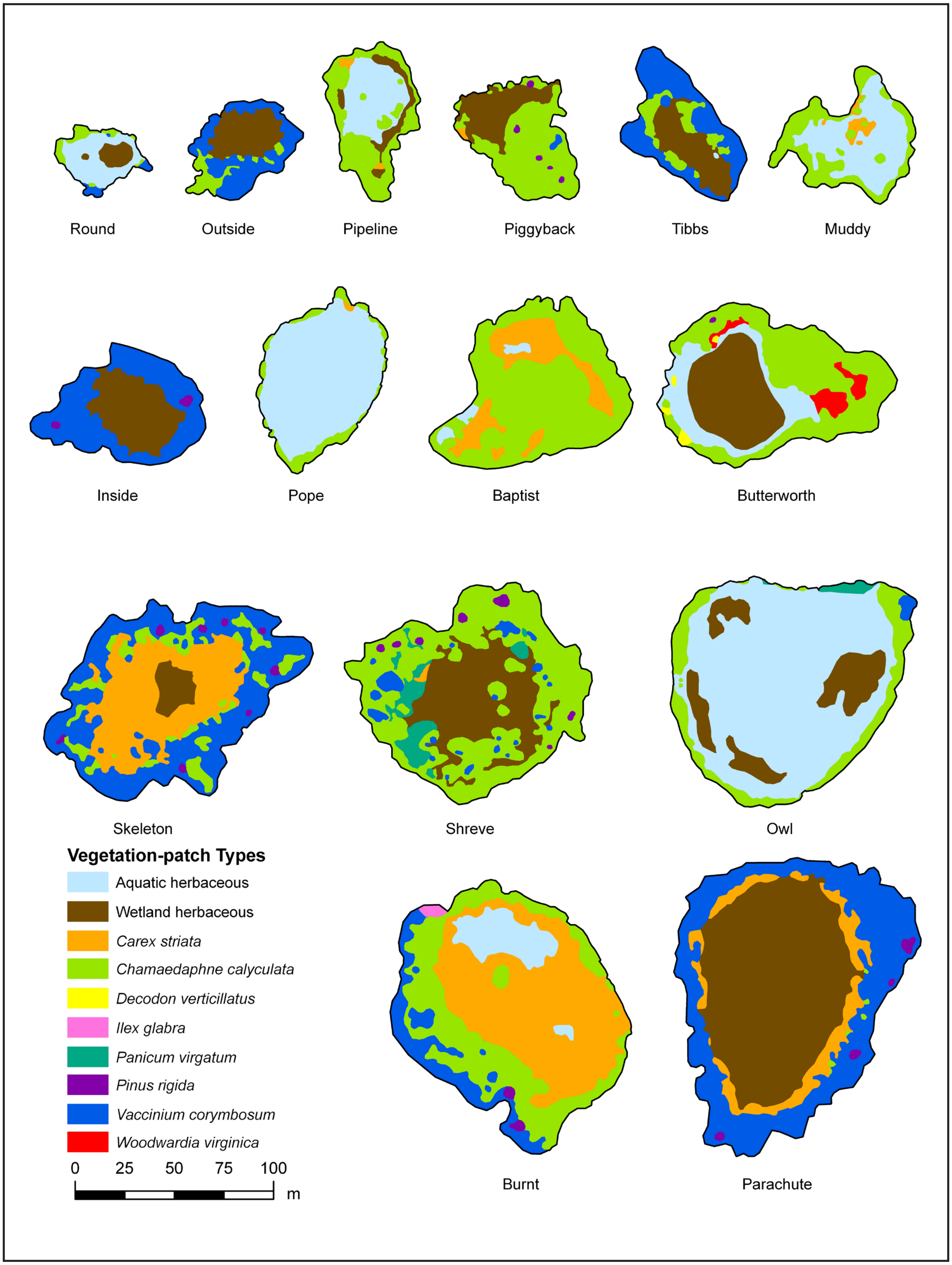

Figure 3. Configuration of vegetation-patch types representing 2005 growing-season conditions for 15 ponds in the New Jersey Pinelands. The aquatic- and wetland-herbaceous types represent a combination of patch types (Table 2).

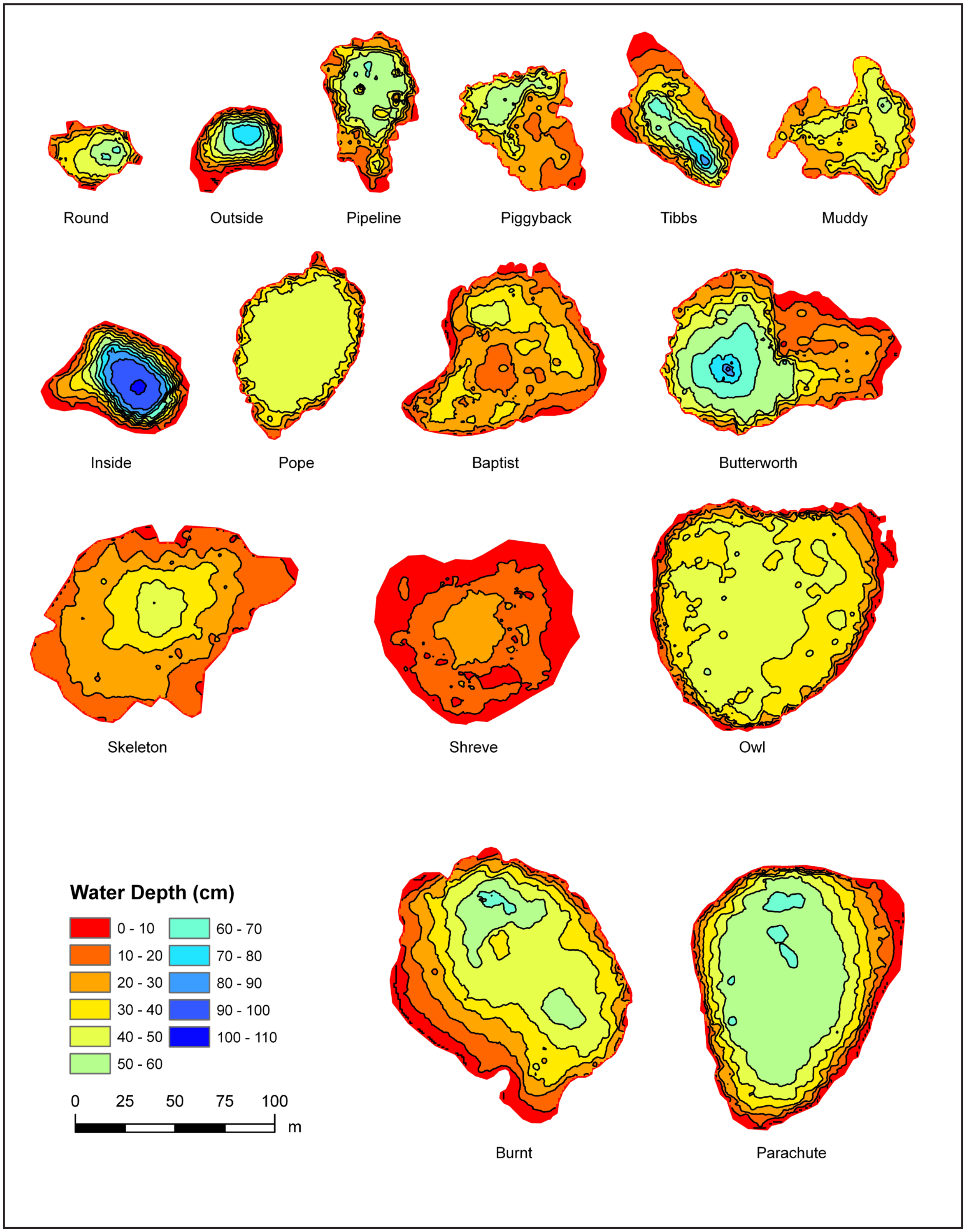

Figure 4. Pond bathymetry representing April 2005 conditions for 15 ponds in the New Jersey Pinelands. Black lines represent water-depth contours at 10-cm intervals.

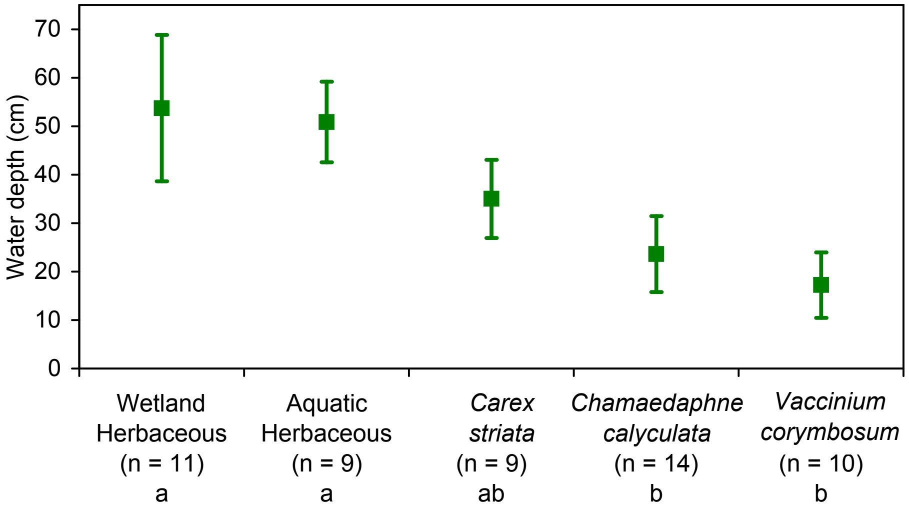

Figure 5. Water levels associated with the most frequently occurring vegetation-patch types for 15 ponds in the New Jersey Pinelands. Mean ± 1 SD values are based on April 2005 water levels, which represented high-water conditions for the study period. The aquatic- and wetland-herbaceous types represent a combination of patch types (Table 2). The number of occurrences for each patch type is given in parentheses. Different letters indicate significant differences based on the Kruskal-Wallis ANOVA.

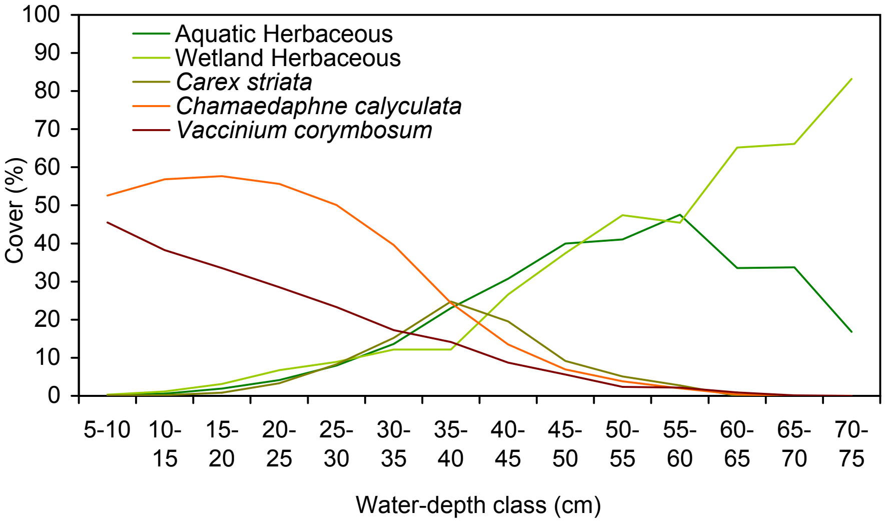

Figure 6. Mean cover for the five most frequently occurring vegetation-patch types within 5-cm water-depth classes. The aquatic- and wetland-herbaceous types represent a combination of patch types (Table 2). Several patch types, whose combined cover never exceeded 3% for any of the water-depth classes, are not shown. Water-depth classes <5 and >75 cm were associated with <1% average pond area and are not shown.

patch-types increased for water-depth reductions ≤15 cm and decreased at water-depth reductions ≥20 cm. These two woody patch types did not decrease beyond initial levels until water levels were reduced by >30 cm for *C. calyculata* and >40 cm for *V. corymbosum*. The aquatic- and wetland-herbaceous types were the most sensitive of the five patch types to simulated water-level reductions. For example, a 15-cm reduction in water depth corresponded to a 54% decrease in the wetland-herbaceous type and a 48% decrease in the aquatic-herbaceous type, whereas the *C. striata* type decreased by only 19% and *C. calyculata* and *V. corymbosum* patch types increased by 26% and 36%, respectively. A 50-cm reduction in water depth resulted in nearly 100% decreases in aquatic- and wetland-herbaceous

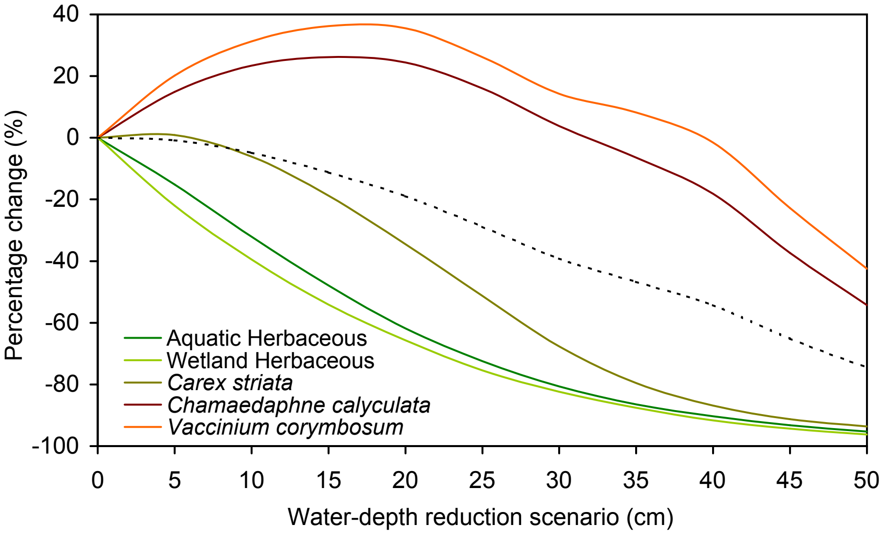

Figure 7. The estimated percentage change in pond area with water levels suitable for dominant vegetation-patch types under various simulated water-depth reduction scenarios. The aquatic- and wetland-herbaceous types represent a combination of patch types (Table 2). The dashed line represents the percentage reduction in all pond-vegetation types combined.

and *C. striata* patch types. The area of combined pond-vegetation types, representing the entire pond as a vegetation community, showed little change at the 5-cm water-depth reduction but decreased monotonically at reductions of ≥10 cm.

Discussion

The patch-type and relative water-level results from this study were comparable to a set of nine Pinelands ponds located in the northwestern portion of the Mullica River watershed that were not affected by historic excavation activities (Zampella and Laidig 2003). The nine ponds were also associated with the Kirkwood-Cohansey aquifer. In that study, *V. corymbosum*, *C. calyculata*, and other woody dominated patches occurred in relatively shallow nearshore areas, *C. striata* patches occupied areas with intermediate water levels, and various aquatic and emergent types occupied deeper water areas associated with the open-water center. The similarities in vegetation and water-level relationships between the two sets of ponds suggest that the predicted vegetation changes due to simulated water-level reductions found in this study have region-wide applicability to assess groundwater withdrawals in the New Jersey Pinelands.

In the construction of the single-pond model, where patch cover was related to water level in 5-cm water-level classes (Figure 6), the increase in wetland-herbaceous cover and decrease in aquatic-herbaceous cover at water depths >60 cm was unexpected. These results may be due, in part, to the increased wetland-species cover for annual and perennial wetland species that grew on dewatered substrate in deep-water zones after the ponds dried. Another confounding factor is that, although the patches were defined based only on dominance, often aquatic and wetland species both occurred in the individual patch types that were combined to form the aquatic- and wetland-herbaceous types (Appendix 2). The distinction of these patch types based on the dominance of wetland or aquatic species may be unwarranted because no consistent patterns were evident in the relative positions of the aquatic- and wetland-herbaceous patches in the four ponds where both patch types occurred (Figure 3) and because water levels associated with the aquatic-herbaceous patches fell within the range of water levels associated with the wetland-herbaceous patches (Figure 5). Regardless, both aquatic- and wetland-herbaceous patch types displayed similar trends (i.e., loss in cover) in response to simulations of increasing water-level drawdown (Figure 7).

Projected increases in woody patch types and decreases in aquatic- and emergent-herbaceous patch types for simulations of water-level reductions ≤20 cm (Figure 7) were generally consistent with reported vegetation changes associated with reduced hydrology in ponds and lakeshores from other areas. For Carolina bays dominated by herbaceous species, drought-induced hydrologic changes led to a decrease in aquatic species and an increase in the abundance of facultative species, including seedlings of tree species (Mulhouse et al. 2005a,b). In another set of bays that were examined over a 15-year period that included two drought events, vegetation changes included a decrease in aquatic-plant cover and an increase in woody and upland species after droughts, whereas aquatic species increased and upland and woody species were eliminated during prolonged periods of inundation (Stroh 2004). Zaremba and Lamont (1993) recorded the incursion of woody species, including *P. rigida*, *Acer rubrum*, and *Clethra alnifolia*, and upland species in a New York coastal plain pond after a multi-year drought and noted that all of these plants were killed when high-water conditions returned. Similarly, dense stands of *P. rigida* saplings became established on some Cape Cod pond shores during a low water-level period due to groundwater withdrawals and low precipitation, with mortality of most saplings recorded after two consecutive years of high water (Craine and Orians 2004). McCarthy (1987) also noted the establishment of tree and shrub species in two southern Pinelands ponds during a period of water-level drawdown. Models describing lakeshore vegetation patterns that suggest that woody plants are killed by high water levels (Keddy and Reznicek 1986, Wilcox and Nichols 2008) are based, in part, on the assumption that lowered water levels allow for woody species colonization. Similar interactions between water-level and shrubby vegetation have been described for Nova Scotian lakeshores (Keddy and Wishue 1989). My model predictions, along with observations from the above studies, support the concept that lowered water levels favor the expansion of woody species into the interior of intermittent ponds and high water levels inhibit shrubs and other woody species from colonizing these areas.

The decrease in area of all five individual and combined patch types assumes replacement of areas previously occupied by pond vegetation with adjacent vegetation types due to the modified site hydrology. In the Pinelands, *P. rigida* lowland forests most commonly occur adjacent to ponds (Zampella and Laidig 2003). *Pinus rigida* lowlands have a mean water level of 55 cm below the soil surface (Laidig et al. 2010), with water levels of 41 and 65 cm for wet and dry lowland types (Zampella et al. 1992), respectively, and lack the standing water that is characteristic of intermittent ponds. Long-term groundwater withdrawals of sufficient magnitude could eliminate standing water in pond areas such that the modified hydrologic regime resembles that of *P. rigida* lowland forests. Thus, intermittent ponds, when viewed broadly as a single vegetation type, could eventually be replaced by the adjacent forest type under these highly modified conditions. Such large-scale replacement of a vegetation type in depressional wetlands has been documented for Carolina bays, where prolonged hydrologic changes brought about by draining were among the factors accounting for the succession of 67 of 125 herbaceous-dominated bays to hardwood-swamp forests during a 41-year study period (Kirkman et al. 1996).

Overlapping water-level ranges associated with individual patch types across the ponds (Figure 5) suggest that factors other than hydrology also may influence the type and extent of vegetation zones in intermittent ponds. Competition between species can affect plant zonation in aquatic and wetland systems (Keddy 1989, Grace and Wetzel 1981). Herbaceous species found in shoreline habitats vary in competitive performance, with large, leafy species and small evergreen rosette plants exhibiting relatively high and low degrees of competitive ability, respectively (Keddy et al. 1994, Gaudet and Keddy 1995). On lakeshores, wetland shrubs restricted the distribution of small evergreen species but had less of an effect on larger, rhizomatous herbs (Keddy 1989).

Catastrophic fire, a major vegetation-shaping force in both uplands and wetlands in the New Jersey Pinelands (Little 1979), may also influence pond-vegetation patterns. Deep-burning fires in depressions within *P. rigida* lowlands may allow standing water to develop, leading to development of a “quaking bog” where water depths are greater than several centimeters deep or extensive *C. calyculata* stands where very shallow water (i.e., water depths of <5 cm or up to 15 cm in wetter periods) conditions prevail (Little 1979). Although I found no evidence for recent catastrophic fire in the vicinity of the study ponds, the presence of elevated root crowns of dead *V. corymbosum* observed in the open-water portion of the shallowest pond in the study suggest that fire may have affected the extent of woody vegetation and open-water zones in this pond.

Herbivory by deer is another factor that exerts a large influence on Pinelands vegetation (Wolgast 1979). Judging from the presence of abundant deer trails and browsed within-pond vegetation at most of the study sites, deer browsing likely affects plant composition and structure in ponds. These potentially confounding factors, in addition to contributing to observed pond-vegetation patterns, may influence the successional trajectories predicted in our vegetation-change scenarios that were based solely on hydrology changes.

Although the results of this study modeled potential changes in pond vegetation under various simulated water-level declines, actual transitions may display variable lag times depending on the vegetation type. Models for hydrologic impacts on herbaceous lakeshore vegetation demonstrated that species composition changed with the length of time that had elapsed since dewatering, with major changes occurring in the second year after dewatering (Wilcox and Nichols 2008). Elsewhere, herbaceous lakeshore vegetation assemblages following drawdown shifted in dominance from bryophytes and annuals to perennial herbs to clonal herbs over a two to three-year period, with the largest changes occurring within the first year of drawdown (Odland and del Moral 2002). Clonal herbs dominated the vegetation assemblage for the remaining ten years of the 13-year study, despite the development of relatively low cover of some woody species that colonized the site. Increases in wetland shrub area in response to periods of low water levels in shoreline wetlands associated with the St. Marys River typically occurred within 5 years of drawdown (Williams and Lyon 1997). Schneider's (1994) flood-history analyses suggested that for trees and shrubs to become established in coastal plain ponds, water-level drawdowns lasting three to four years are required. Large-scale transitions from pond-vegetation to forest communities would likely take even longer. Non-hydrologic factors, such as those previously mentioned, may also influence the length of time over which herbaceous- and woody-vegetation transitions occur after hydrologic regimes have been modified.

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Appendix 1. Herbaceous-, woody-, and *Sphagnum*-species found at 15 ponds in the New Jersey Pinelands. Percentage-cover values are based on 1-m^2 sample plots and refer to the percentage of pond area occupied by a species. A "P" represents species that were either present at less than 1% cover or that were present outside of the 1-m^2 sample plots. Cover for individual *Sphagnum* spp. was not measured.

	Ponds														
Species	Baptist	Burnt	Butterworth	Inside	Muddy	Outside	Owl	Parachute	Piggyback	Pipeline	Pope	Round	Shreve	Skeleton	Tibbs
Herbaceous Species:															
Amphicarpum purshii	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-
Brasenia schreberi	-	5.6	2.3	-	-	-	-	-	-	P	8.4	-	-	-	1.9
Carex striata	13.0	29.6	4.0	-	18.7	-	P	8.5	2.2	1.3	P	P	P	28.3	-
Cladium mariscoides	-	-	-	-	-	-	5.6	-	P	-	-	-	-	-	-
Cyperus dentatus	-	-	-	-	-	-	-	P	-	-	-	-	P	P	-
Decodon verticillatus	-	P	4.1	-	-	-	P	-	-	2.8	-	-	-	-	-
Drosera filiformis	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera intermedia	P	P	-	P	-	P	P	P	-	-	P	P	P	P	P
Dulichium arundinaceum	P	P	P	-	-	-	-	-	-	7.8	-	-	-	-	P
Eleocharis flavescens var. *olivacea*	-	P	-	P	-	P	P	P	P	P	P	P	P	P	P
Eleocharis microcarpa	-	P	-	P	-	P	-	-	P	P	-	6.5	-	-	-
Eleocharis robbinsii	-	1.6	-	-	-	-	27.4	P	-	-	P	-	-	-	-
Eleocharis tricostata	-	-	-	-	-	P	-	-	-	-	-	-	-	P	-
Erianthus giganteus	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-
Eriocaulon aquaticum	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-
Eriocaulon compressum	-	3.2	-	-	-	-	2.9	-	-	-	3.1	-	-	-	-
Euthamia tenuifolia	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-
Fimbristylis autumnalis	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-
Hypericum canadense	-	-	-	2.3	-	1.4	P	P	-	-	-	-	-	-	P
Juncus militaris	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-
Juncus pelocarpus	-	-	-	P	-	P	7.5	P	-	-	P	-	P	P	-
Nuphar variegata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P
Nymphaea odorata	P	P	P	-	-	P	2.2	-	-	P	P	-	P	-	P
Nymphoides cordata	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-
Orontium aquaticum	-	P	P	-	-	-	-	-	-	-	-	-	-	-	-
Panicum longifolium	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-
Panicum verrucosum	-	P	-	P	-	P	P	P	-	-	-	P	P	P	P
Panicum virgatum	-	-	-	-	-	-	P	-	-	-	-	-	5.0	-	-
Panicum spretum	-	P	-	P	-	P	P	-	-	-	-	-	-	-	-
Proserpinaca pectinata	-	-	-	-	-	-	P	-	P	-	-	P	-	-	-
Rhexia virginica	-	-	-	P	-	P	P	P	-	-	-	-	P	-	P
Rhynchospora alba	-	-	-	-	-	P	P	P	-	-	-	-	1.4	-	-
Rhynchospora fusca	-	-	-	P	-	-	-	-	-	-	-	-	2.5	-	-
Rhynchospora inundata	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-
Scirpus cyperinus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.1
Scirpus subterminalis	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-
Scleria reticularis	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-
Triadenum virginicum	-	-	-	-	-	-	P	P	-	-	-	-	-	1.2	-
Utricularia fibrosa	P	2.2	17.9	-	-	-	3.3	-	-	10.0	45.0	22.6	P	-	-
Utricularia subulata	P	-	-	P	-	P	P	P	-	-	-	-	P	P	-
Utricularia geminiscapa	-	-	-	-	29.2	-	P	-	P	P	-	P	-	-	P
Woodwardia virginica	P	P	4.8	-	P	-	P	-	P	-	P	P	-	-	-
Xyris difformis	P	P	-	P	-	P	1.0	P	-	-	-	-	11.3	P	P
Xyris smalliana	P	P	-	-	-	-	P	-	-	-	-	-	-	-	-

Appendix 1. Continued.

Woody Species:															
Acer rubrum	P	2.1	P	P	P	3.8	P	P	5.7	P	8.5	9.2	P	P	P
Acer rubrum (seedling)	-	-	P	-	P	-	-	-	2.4	P	-	-	-	-	-
Amelanchier canadensis	-	-	-	-	P	-	P	-	P	P	P	P	-	-	-
Aronia arbutifolia	P	P	P	-	P	P	P	-	P	P	P	-	P	P	P
Betula populifolia	-	-	-	-	-	-	-	-	-	P	-	-	-	-	P
Cephalanthus occidentalis	-	P	-	P	-	-	-	-	-	2.6	-	-	-	-	-
Chamaecyparis thyoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P
Chamaedaphne calyculata	70.1	26.7	40.1	-	30.4	12.2	11.9	P	58.6	40.7	7.8	10.7	44.1	11.2	14.7
Clethra alnifolia	P	P	-	-	P	-	P	-	P	P	-	P	-	-	-
Eubotrys racemosa	P	P	P	P	P	P	P	P	P	P	P	P	P	-	P
Gaultheria procumbens	P	-	-	-	-	-	-	-	-	-	P	-	-	-	-
Gaylussacia baccata	-	-	P	-	-	-	-	-	P	-	-	-	P	-	-
Gaylussacia dumosa	P	-	P	-	P	-	P	-	2.8	P	P	-	-	-	-
Gaylussacia frondosa	P	-	P	-	P	-	P	-	P	P	P	P	P	-	-
Ilex glabra	P	P	P	-	P	P	P	-	P	P	P	P	P	-	-
Kalmia angustifolia	1.2	2.2	P	-	P	P	P	-	1.7	2.0	P	P	P	P	P
Lyonia ligustrina	-	-	P	-	P	-	-	-	P	-	-	-	-	-	-
Lyonia mariana	-	P	-	P	P	P	P	P	-	P	-	-	P	P	P
Nyssa sylvatica	P	P	P	P	P	-	P	P	-	P	P	P	-	-	P
Pinus rigida	P	P	P	P	P	1.5	P	P	P	P	P	P	P	P	P
Rhododendron viscosum	-	-	-	-	P	-	-	-	P	-	P	P	-	-	-
Sassafras albidum	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-
Smilax rotundifolia	P	P	P	P	-	P	P	P	P	P	P	P	-	P	P
Vaccinium corymbosum	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Vaccinium macrocarpon	-	-	-	-	P	-	P	-	P	-	P	-	-	-	-
Sphagnum Species:															
Sphagnum angermanicum	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-
Sphagnum bartlettianum	P	-	P	-	P	-	P	-	P	P	-	-	-	-	-
Sphagnum cuspidatum	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Sphagnum flavicomans	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-
Sphagnum henryense	P	-	-	-	-	-	-	-	-	P	-	-	-	-	-
Sphagnum macrophyllum	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-
Sphagnum magellanicum	P	-	P	-	P	-	-	-	P	P	P	P	-	-	-
Sphagnum palustre	-	-	-	-	-	-	-	-	P	P	-	-	-	-	-
Sphagnum papillosum	-	-	-	-	-	-	-	-	P	-	-	P	-	-	-
Sphagnum pulchrum	P	P	P	-	P	-	P	-	P	P	P	P	-	-	-
Sphagnum recurvum	-	P	P	-	P	-	-	-	P	P	P	P	-	-	-
Sphagnum tenerum	-	-	P	-	-	-	-	-	-	-	-	P	-	-	-

Appendix 2. Species cover in 22 vegetation-patch types at 15 ponds in the New Jersey Pinelands. Values represent mean percentage cover based on 1-m^2 sample plots. A "P" represents species that were present at less than 0.1% mean cover. Three patch types, including *Vaccinium corymbosum*, *Ilex glabra*, and *Pinus rigida* types, where vegetation cover was not measured, are not listed.

	Vegetation-patch Types																					
Species	Mixed herbaceous	*Brasenia schreberi*	*Carex striata*	*Chamaedaphne calyculata*	*Cladium mariscoides*	*Decodon verticillatus*	*Dulichium arundinaceum*	*Eleocharis flavescens*	*Eleocharis microcarpa*	*Eleocharis robbinsii*	*Eriocaulon compressum*	*Hypericum canadense*	*Juncus pelocarpus*	*Nymphaea odorata*	*Panicum virgatum*	*Rhynchospora fusca*	*Scirpus cyperinus*	*Utricularia fibrosa*	*Utricularia geminiscapa*	*Utricularia subulata*	*Woodwardia virginica*	*Xyris difformis*
<u>Herbaceous species:</u>																						
Brasenia schreberi	1.3	65	P	-	-	-	-	-	-	7.0	-	-	-	-	-	-	-	0.5	-	-	-	-
Carex striata	P	0.2	66	4.3	-	3.3	-	-	-	0.3	1.0	-	-	1.0	2.5	-	-	0.3	0.7	1.5	15	1.1
Cladium mariscoides	-	-	-	-	39	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Cyperus dentatus	-	-	-	-	-	-	-	0.8	-	-	-	-	-	-	-	0.3	-	-	-	-	-	1.2
Decodon verticillatus	-	-	-	1.0	-	90	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-
Drosera intermedia	0.4	-	0.3	P	0.2	-	-	0.8	-	P	0.5	-	0.3	-	0.8	0.3	-	P	-	7.5	-	1.0
Dulichium arundinaceum	P	-	0.2	0.1	-	-	61	-	-	-	-	-	-	3.0	-	-	-	1.9	-	-	-	-
Eleocharis flavescens v. olivacea	0.4	0.1	-	-	-	-	-	15	0.4	-	-	0.4	0.4	-	-	-	-	0.2	-	-	-	P
Eleocharis microcarpa	0.2	-	-	-	-	-	-	-	26	-	-	0.7	-	-	-	-	-	0.1	-	-	-	-
Eleocharis robbinssii	-	4.9	-	-	15	-	-	-	-	37	12	-	6.3	-	-	-	-	-	-	-	-	-
Eleocharis tricostata	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eriocaulon compressum	-	1.7	0.5	-	1.9	-	-	-	-	1.1	50	-	0.3	-	-	-	-	1.1	-	-	-	-
Fimbristylis autumnalis	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypericum canadense	0.1	-	-	-	-	-	-	-	-	-	-	8.6	-	-	-	-	-	-	-	-	-	-
Juncus pelocarpus	0.3	-	-	-	2.3	-	-	0.2	-	4.9	2.3	-	14	-	-	1.3	-	P	-	-	-	2.1
Nymphaea odorata	-	0.1	P	-	0.9	-	-	-	-	1.4	-	-	3.9	13	-	-	-	0.2	-	-	-	-
Nymphoides cordata	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-
Panicum spretum	-	-	P	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-
Panicum verrucosum	0.5	-	P	-	-	-	-	1	-	-	0.3	0.8	0.3	-	0.7	0.3	-	P	-	-	-	1.2
Panicum virgatum	-	-	1.2	P	-	-	-	-	-	P	-	-	-	-	70	5.3	-	-	-	-	-	4.2
Proserpinaca pectinata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-
Rhexia virginica	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3
Rhyncospora alba	-	-	-	P	-	-	-	-	-	-	-	-	-	-	0.2	0.7	-	-	-	-	-	5.1
Rhyncospora fusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60	-	-	-	-	-	1.0
Scirpus cyperinus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52	-	-	-	-	-
Sphagnum spp.	29	26	72	74	82	100	100	100	33	14	18	26	16	48	97	65	4.5	46	23	76	100	30
Triadenum virginicum	-	-	0.4	-	-	-	-	0.6	-	-	-	-	-	-	1.8	-	-	-	-	-	-	-
Utricularia fibrosa	0.1	10	1.3	P	2.4	13	5.0	-	0.4	1.6	-	-	11.3	-	-	-	-	54	-	-	6.0	-
Utricularia geminscapa	-	-	2.0	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48	-	-	-
Utricularia subulata	0.1	-	0.1	-	-	-	-	0.2	-	-	-	-	-	-	0.1	0.3	-	-	-	14	-	0.7
Woodwardia virginica	-	-	P	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59	-
Xyris difformis	0.2	-	0.4	0	0.8	-	-	0.4	-	0.7	-	0.1	-	-	0.3	11	-	-	-	1.5	-	40
Xyris smalliana	-	0.1	P	-	-	-	-	-	-	-	0.8	-	0.1	-	-	-	-	-	-	-	-	-
<u>Woody species:</u>																						
Acer rubrum	-	-	11	12	-	28	-	-	-	-	-	-	-	-	-	-	-	2.4	-	-	-	-
Acer rubrum (seedling)	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aronia arbutifolia	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cepalanthus occidentalis	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chamaedaphne calyculata	-	-	5.7	87	-	1.0	-	-	-	-	-	-	-	-	1.0	-	-	P	-	1.5	0.7	-
Gaylussacia baccata	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gaylussacia dumosa	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gaylussacia frondosa	-	-	3.9	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilex glabra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-
Kalmia angustifolia	-	-	6.8	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinus rigida	-	-	-	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Smilax rotundifolia	-	-	P	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vaccinium corymbosum	-	-	P	0.1	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-
Vaccinium macrocarpon	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-