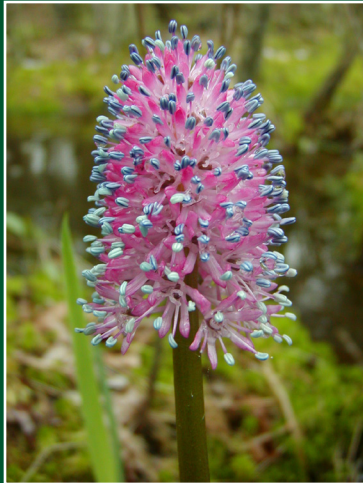


KIRKWOOD-COHANSEY PROJECT

HYDROLOGIC REGIMES ASSOCIATED WITH *HELONIAS BULLATA* L. (SWAMP PINK) AND THE POTENTIAL IMPACT OF SIMULATED WATER-LEVEL REDUCTIONS



Cover: A group of *Helonias bullata* (swamp pink) plants growing in an Atlantic white cedar swamp and a raceme of pink flowers (inset). Photographs taken by Kim J. Laidig.

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ABSTRACT

The conservation of *Helonias bullata* L. (swamp pink), a federally listed species, is closely associated with the maintenance of appropriate site hydrology. Although changes to site hydrology have been implicated in the degradation and extirpation of some *Helonias bullata* occurrences, quantitative hydrologic data with which to assess potential hydrologic impacts to the species are lacking. We characterized site hydrology, substrate, topography, tree-canopy cover, and hydrologic regimes associated with *Helonias bullata* at two colonies located along small streams in the New Jersey Pinelands and assessed the potential impact of simulated water-level reductions on the species and its habitat. Over the two-year study period, surface-water levels at the two colonies fluctuated by 11.9 and 27.9 cm. Sites were characterized by muck substrate and variable topography with steep-sided hummocks in and along stream channels. Tree-canopy cover above the two colonies was 36% and 9% less than canopy cover in the adjacent forests. The pronounced difference in water levels associated with *Helonias bullata* plants compared with water levels associated with points where the plant was not present suggested that *Helonias bullata* was not uniformly distributed at the sites in relation to water table. *Helonias bullata* clusters, composed of groups of individual plants, were typically associated with the emergent portions of hummocks in and along the stream channels. Based on measurements at 958 clusters, the 2-year median water level at the two sites was 7.9 and 10.9 cm below the base of the clusters. More than 90% of the total cluster area at both sites was associated with water levels between -5.0 (submerged) and 19.9 cm (exposed). The greatest total cluster area was associated with water levels between 5.0 and 9.9 cm, which may be the optimal water-level range for *Helonias bullata*. A relatively small simulated water-level drawdown of 15 cm exposed more than 30% of the cluster area at both sites to extreme hydrologic conditions, which we defined as the water level beyond which <10% of the total existing *Helonias bullata* cover occurred at our sites (i.e., ≥ 20 cm below the base of the clusters). A larger simulated water-level reduction of 30 cm exposed all or nearly all of the cluster area to extreme conditions. Simulated impacts on habitat were less pronounced for smaller drawdowns because losses of suitable habitat (i.e., habitat that occurs within the 10th and 90th percentiles of measured water levels associated with *Helonias bullata*) were countered by dewatering of habitat that was previously submerged. The extent to which this dewatered habitat can compensate for losses in suitable habitat depends upon the potential for *Helonias bullata* to colonize the dewatered habitat. The hydrologic relationships described in this study may inform restoration efforts for this species and provide the basis for assessing potential impacts to *Helonias bullata* sites that are subjected to hydrologic variation.

INTRODUCTION

One of the fundamental steps required for developing effective rare-plant recovery programs is the identification of ecological factors that pose the greatest threat to the rare species (Schemske et al. 1994). Hydrology is among the ecological factors regarded as important for the maintenance of *Helonias bullata* L. (swamp pink), a wetland species that was federally listed in 1988 (Hecht 1988, U.S. Fish and Wildlife Service 1991). Changes in hydrology have been implicated as a contributing factor in the degradation of *Helonias bullata* habitat and extirpation of the species at some locations in New Jersey (Gordon 1989, Arsenault 1995, Dodds 1996a, Johnson 1998). Despite the emphasis placed on maintaining appropriate site hydrology for the conservation of *Helonias bullata*, quantitative hydrologic data with which to assess potential

hydrologic impacts to the species are lacking.

Helonias bullata (hereafter, the species will be referred to as *Helonias* because the genus is monotypic) is a perennial herb characterized by a short stout rhizome, evergreen leaves that form a flat basal rosette, and a tall scape bearing a terminal raceme of pink flowers (Godfrey and Wooten 1979, Gleason and Cronquist 1991). This wetland species is associated with swamps and bogs of coastal plain and mountainous areas in the eastern United States (Gleason and Cronquist 1991). *Helonias* once occurred from New York to Georgia, but because the only known New York site was extirpated, the species currently does not extend north of New Jersey (U. S. Fish and Wildlife Service 1991). The species is considered rare and locally distributed throughout its range with the greatest number of sites occurring in southern New Jersey (Brown 1910, U. S. Fish and Wildlife Service 1991). Brown

(1910) described *Helonias* habitat in southern New Jersey as consisting of “shady swamps along the streams or near their headwaters.” Swamp types associated with *Helonias* include both hardwood and *Chamaecyparis thyoides* (Atlantic white cedar) wetlands (U. S. Fish and Wildlife Service 1991). Though Brown (1910) did not consider *Helonias* to be a characteristic New Jersey Pinelands (Pine Barrens) species, he noted its presence in several Pinelands locations. Stone (1911) viewed *Helonias* as a wide-ranging species associated with both the Pine Barrens and areas located to the west of the region and considered the species “one of the most characteristic plants of the southern half of New Jersey.” *Helonias* is currently believed to occur at 139 sites in southern New Jersey, with 25 sites located in the Pinelands area (U. S. Fish and Wildlife Service, *unpublished data*).

The present study was conducted as part of a larger research project that will assess potential hydrologic impacts on aquatic and wetland systems associated with ground-water withdrawals from the Kirkwood-Cohansey aquifer due to the pumping of water-supply wells. This water-table aquifer, composed primarily of sand, silt, gravel, and clay deposits associated with the surface Cohansey Sand and underlying Kirkwood Formation, is the principal aquifer of the New Jersey Pinelands (Rhodehamel 1979a, b, Zapeca 1989). Ground-water withdrawals from unconfined portions of the Kirkwood-Cohansey aquifer currently supply 126 public water-supply wells in the Pinelands region (New Jersey Department of Environmental Protection 2007) with additional withdrawals associated with private domestic wells and commercial and agricultural uses. In an unconfined aquifer, groundwater pumping lowers the water table within a cone of depression that extends laterally away from the well (Winter 1988). Direct wetland impacts can occur if the cone of depression intersects the wetland. The *Helonias* portion of the Kirkwood-Cohansey project addresses two questions. First, what hydrologic regimes and other site characteristics are associated with *Helonias* in the Pinelands? Second, what are the potential impacts to *Helonias* and its habitat associated with simulated water-level reductions?

METHODS

Study-site Selection

Two *Helonias* colonies, which we refer to as the Cooks and Shinns colonies, were selected from an inventory of Pinelands sites (U. S. Fish and Wildlife Service, *unpublished data*). The presence of an adequate number (>100) of *Helonias* plants, the dominance of *C. thyoides* in the tree canopy, and negligible upstream agricultural and residential land uses were major site-selection criteria. The Cooks colony extends approximately 40 m along a seepage tributary associated with Cooks Branch, a first-order stream within the Cedar Creek basin (Figure 1A). The Shinns colony extends approximately 80 m along Shinns Branch, a first-order North Branch Rancocas Creek tributary within the Delaware River basin. The colonies are located on muck soils in extant *C. thyoides* forests in and along the channels of slow-moving streams. Although no water quality data were collected at the two study sites during the study, nearby streams draining forest land in the Cedar Creek and North Branch Rancocas Creek are characterized by low pH and low specific conductance (Zampella et al. 2003, 2006).

Two-meter-wide, variable-length, belt transects were established at each study site. Five belt transects were established at Cooks and eight at Shinns. Belt transects were oriented perpendicular to the stream channels and extended to the boundaries of the *Helonias* population on either side of the stream. Transect length varied according to the width of the colony and ranged from 3 to 23 m (mean = 16.3 m) at Cooks and from 2 to 13 m (mean = 7.3 m) at Shinns. Approximately 5 m separated individual belt transects at each study site. A staff gauge was placed in the stream channel at a point located in the center of each belt transect to measure water levels.

Helonias and Associated Vegetation

***Helonias* Clusters.** *Helonias* is a clonal herb that can reproduce vegetatively via rhizomes (Sutter 1984), forming clusters of closely spaced rosettes. Our sampling unit consisted of individual clusters. We defined a cluster as one or more *Helonias* rosettes with overlapping leaves (Figure 1B). For each cluster, we recorded the number



Figure 1. A. Atlantic white cedar swamp and seepage stream associated with the Cooks *Helonias bullata* colony. B. *Helonias bullata* cluster formed by the overlapping basal leaves of multiple rosettes. C. Isolated, steep-sided hummocks associated with *Helonias bullata* clusters within the stream channel. D. Growth of *Helonias bullata* plants near the water surface on submerged hummocks.

of rosettes and flowering stems present. We measured the minimum and maximum diameter of each cluster and, assuming a circular cluster shape, used the mean diameter to calculate its area.

Associated Species. At each *Helonias* cluster, we recorded the presence of *Sphagnum* spp. and all woody and herbaceous species found within an imaginary cylinder formed by the circular perimeter of the cluster. The presence of individual canopy-tree species located directly above each cluster was determined with a vertical densitometer which was used to provide a single-point measurement of canopy-tree presence. Vegetation sampling was conducted at Cooks in 2004 and at Shinns in 2005. Taxonomic nomenclature followed Gleason and Cronquist (1991).

Environmental Factors

Site Topography, Hydrology, Muck Depth, and Shading. We measured water levels at the staff gauges from October 2004 through September 2006. We generally followed a biweekly sampling schedule and measured all staff gauges at the Cooks and Shinns sites on the same day. All water-level measurements were collected at least three days after a significant rain event (> 2.5 cm).

With the associated staff gauge as a reference point, we used a transit level and a stadia rod to measure the relative elevation of the submerged and exposed land surface at points located at 0.5-m intervals along the center of each belt transect. Points within the perimeter of a *Helonias* cluster were not measured. The elevation measurements provided the basis to calculate water levels relative to the land surface at each point for each water-level sampling date using the associated biweekly staff-gauge water-level measurement as a reference. Muck depth, defined as the distance from the substrate surface to underlying mineral sediments, was measured with a metal probe at 1.0-m intervals along the center of each belt transect.

To estimate shading above a *Helonias* colony and in an adjacent area of forest, a concave spherical crown densitometer was used to measure canopy cover above three points along each transect, including the transect midpoint and points located 10 m beyond the transect endpoint on either side of a *Helonias* colony. By measuring canopy cover at the transect midpoint and 10 m beyond

the transect endpoints, we avoided overlapping spherical crown-densitometer measurements. Each canopy-cover measurement is a mean value based on four spherical crown-densitometer readings taken at a single location. Two adjacent-forest canopy measurements were not collected at Cooks because the presence of cut stumps in the immediate vicinity indicated recent tree cutting had occurred.

Helonias Water Levels. A level and chain was used to measure the vertical distance from the base of each *Helonias* cluster to the surface of standing water. For clusters with more than one rosette, the water levels associated with the highest and the lowest rosettes were averaged. Using these measurements and the staff-gauge readings collected on the same date as references, we calculated water levels relative to the base of each cluster for each water-level sampling date.

Data Analysis

Helonias and Associated Species. For each site, we prepared summary statistics describing the number of *Helonias* rosettes per cluster, cluster size, and flowering-cluster size and tallied the total number of rosettes and flowering stems. Using individual *Helonias* clusters as a sampling unit, we calculated the frequency of occurrence of associated plant species and mean species richness for each site. We tallied herbaceous, woody, and total species richness for each site.

Hydrologic Conditions. To determine if hydrologic conditions during our study period were representative of long-term conditions, we used monthly mean-discharge data for the McDonalds Branch hydrologic benchmark station (Mast and Turk 1999) and a Mann-Whitney test to compare study-period and long-term stream discharge regimes (October 1953 to September 2005). The data were accessed online from the U. S. Geological Survey Surface-Water Data for USA webpage (<http://waterdata.usgs.gov/nwis/sw>).

Site Topography, Hydrology, Muck Depth, and Shading. We graphically evaluated the relative topographic relief of representative transects. Using the individual transect-point data, we calculated median water levels, representing the distance from the surface of submerged (negative values) or exposed (positive values) land surface to the surface of standing water for each site for each

water-level sampling date. Sampling-date medians were used to construct hydrographs for the two sites, and Spearman rank correlation was used to relate the sampling-date medians between sites. We calculated median study-period water levels for each individual transect point and used these values to calculate a site-wide median. Using the 2-yr-median water levels associated with each transect point, we calculated the percentage of transect points associated with water levels grouped in 5-cm classes. Mean muck thickness was also determined for each site. Mann-Whitney tests were used to compare the tree-canopy cover above the *Helonias* colonies with canopy cover in the adjacent forest.

Helonias Water-Level Relationships

Using the individual cluster data, we calculated a median *Helonias*-cluster water level for each site for each water-level sampling date and a median study-period water level for each individual cluster. Water levels represent the distance from the base of submerged (negative values) or emergent (positive values) *Helonias* clusters to the surface of standing water. The individual study-period medians were used to calculate a site-wide median water level. Using the area of each individual cluster and its associated 2-yr-median water level, we calculated the total *Helonias*-cluster area associated with water levels grouped in 5-cm classes. We used Spearman rank correlation to relate the percentage of *Helonias*-cluster area at 5-cm water-level classes between the two sites. Spearman rank correlation was also used to relate the percentage of *Helonias*-cluster area and the percentage of transect points at the 5-cm water-level classes within each site. We graphically compared the 2-yr-median *Helonias*-cluster and transect-point water levels for each site. An alpha level of 0.05 was used to assess significance for all statistical tests, which were performed using Statistica 7.1 (StatSoft, Inc., Tulsa, OK, 2005). Variance was ± 1 SD unless otherwise indicated.

Water-level Reduction Scenarios

We assessed the potential impact of simulated water-level reductions on *Helonias* clusters and habitat under permanent, median water-level reduction scenarios. Reductions were applied in 5-cm increments up to a maximum of 100 cm. For each site, we determined the percentage of existing

Helonias-cluster area that would be exposed to extreme hydrologic conditions (i.e., extreme water levels). Extreme hydrologic conditions were based on the range of water levels associated with the natural occurrence of *Helonias* as measured in this study. We defined extreme conditions in two ways, including the median water level at the drier end of the hydrologic gradient beyond which <10% of the total existing *Helonias* cover occurred and the median water level beyond which *Helonias* was absent. We determined the percentage of suitable habitat remaining under different mean water-level reduction scenarios. Suitable habitat was defined as transect points that occurred within the 10th and 90th percentile water levels where *Helonias* was found.

RESULTS

Helonias and Associated Species

Helonias Clusters. We examined 805 *Helonias* clusters at Cooks and 153 *Helonias* clusters at Shinns (Table 1). For each site, the mean number of rosettes per cluster was 1.9, and clusters composed of a single rosette accounted for approximately 70% of all clusters. Fifteen flowering stems associated with 12 clusters were observed at Cooks. Flowering clusters were relatively large. Although no flowering occurred at Shinns during the year when vegetation measurements were completed, one to two flowering stems were observed in previous and subsequent years while conducting other aspects of the study.

Associated Species. Based on vertical-densitometer measurements of tree-canopy species above *Helonias* clusters, *C. thyoides* occupied 92% of the canopy at Cooks and 80% of the canopy at Shinns. *Magnolia virginiana* represented 7% of the canopy at Cooks and 19% of the canopy at Shinns. The combined cover of *Nyssa sylvatica* and *Acer rubrum* represented less than 2% of the canopy at both sites.

Forty-six understory vascular plant species, including 22 herbaceous and 24 woody species, were associated with *Helonias* clusters at the two study sites, with higher total, herbaceous, and woody species richness found at Cooks (Table 2). Mean associated species richness was 2.4 ± 1.8 at Cooks and 1.8 ± 1.2 at Shinns. *Sphagnum* was associated with 78% of the *Helonias* clusters at Cooks and 26% of the clusters at Shinns.

Environmental Factors

Hydrologic Conditions. Mean monthly discharge at McDonalds Branch for the study period (2.01 ± 0.65 cfs) did not differ significantly from long-term (October 1954 to September 2005) mean monthly discharge (2.13 ± 1.00 cfs) (Mann-Whitney test, $p = 0.895$).

Site Topography, Hydrology, Muck Depth, and Shading. Topography associated with the *Helonias* transects was highly variable with steep slopes associated with many of the hummocks (Figure 1C). For the 2-yr study period, median site-wide water levels, measured as the distance from the surface of submerged (-) or exposed (+) land surface to the surface of standing water, were 0.3 cm at Cooks and -12.9 cm at Shinns (Table 1, Figure 2), with study-period medians for individual transect points ranging from -70 to 50 cm for Cooks and -94 to 33 cm for Shinns.

Water-level patterns at Cooks and Shinns were similar, which is reflected by the strong correlation between median monthly water levels recorded at the two sites ($r = 0.79$, $p < 0.001$). Water levels were generally higher during the winter and early-spring months and lower in the summer and fall months. Median sampling-date water-levels for the study period ranged from -6.5 to 5.4 (range = 11.9 cm) at Cooks and -1.3 to 26.6 (range = 27.9 cm) at Shinns.

Mean muck depth was greater than 100 cm at both sites (Table 1). Shallow muck or the absence of muck was associated with portions of some of the hummocks with dense roots and decaying stumps or logs.

Based on spherical crown-densimeter measurements, tree-canopy cover above the two colonies was 36% and 9% less than canopy cover in

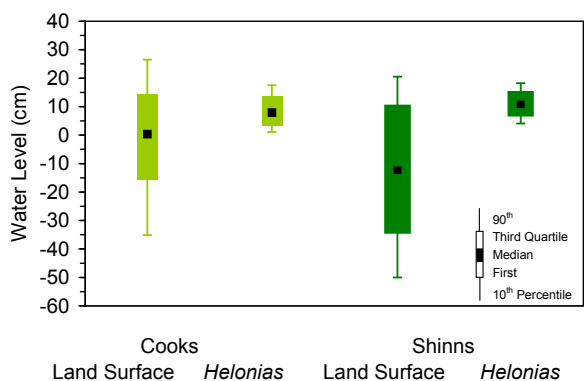


Figure 2. Water levels relative to the land surface and the base of *Helonias* clusters for Cooks (land surface $n = 161$, *Helonias* $n = 805$) and Shinns (land surface $n = 163$, *Helonias* $n = 153$) for October 2004 – September 2006. Negative water-level values indicate submergence.

the adjacent forests (Table 1). Differences in canopy cover between the *Helonias* colony and the adjacent forest were significant at both sites (Mann-Whitney test, Cooks: $p < 0.001$; Shinns: $p < 0.001$).

Helonias Water-level Relationships

Helonias plants were associated with hummocks in and along the edge of the poorly defined stream channels at both sites. For the 2-yr study period, median *Helonias*-cluster water levels on individual water-level measurement dates ranged from 2.7 to 13.8 cm for Cooks and -2.5 to 25.0 cm for Shinns (Figure 3). Negative median water-level values at Shinns on November 2004 and February 2005 indicate that most of the clusters were submerged on those dates.

The site-wide study-period median water levels, based on 2-yr-median water levels associated with individual *Helonias*-clusters, was 7.9 cm at Cooks and 10.9 cm at Shinns (Figure 2, Table 1), with

Table 1. *Helonias*-cluster and environmental characteristics for two sites in the New Jersey Pinelands. Transect-point water levels represent the vertical distance from the land surface to the water surface. *Helonias*-cluster water levels represent the vertical distance from the base of *Helonias* clusters to the water surface. Negative water-level values indicate submergence.

| Variable | Cooks | | | Shinns | | |
|---|-------|--------|-----------------|--------|--------|------------------|
| | n | Median | Mean \pm 1 SD | n | Median | Mean \pm 1 SD |
| <i>Helonias</i> rosettes per cluster | 805 | 1.0 | 1.9 \pm 2.3 | 153 | 1.0 | 1.9 \pm 2.4 |
| <i>Helonias</i> cluster size (cm ²) | 805 | 14.5 | 267 \pm 837 | 153 | 35.8 | 172 \pm 557 |
| <i>Helonias</i> flowering cluster size (cm ²) | 12 | 1380 | 2330 \pm 2450 | - | - | - |
| <i>Helonias</i> cluster water levels (cm) | 805 | 7.9 | 9.1 \pm 6.8 | 153 | 10.9 | 10.9 \pm 6.1 |
| Transect point water levels (cm) | 161 | 0.3 | -1.9 \pm 24.2 | 163 | -12.9 | -14.6 \pm 26.0 |
| Muck depth (cm) | 96 | 105 | 103 \pm 29 | 66 | 139 | 139 \pm 31 |
| Colony canopy cover (%) | 5 | 58.5 | 47.6 \pm 21.0 | 8 | 81.0 | 82.3 \pm 3.5 |
| Adjacent forest canopy cover (%) | 8 | 84.9 | 83.5 \pm 7.4 | 16 | 91.4 | 91.5 \pm 3.1 |

Table 2. Herbaceous and woody understory species associated with *Helonias* clusters at Cooks (n = 805) and Shinns (n = 153). Values represent the percentage of clusters where a species was present. Tree species in the understory are present as seedlings or saplings. Species are ordered by the maximum frequency of occurrence for the two sites within herbaceous and woody plant groups.

| Species | Cooks | Shinns |
|--------------------------------|-------|--------|
| Herbaceous plants: | | |
| <i>Rhynchospora alba</i> | 30.3 | - |
| <i>Carex striata</i> | 22.6 | - |
| <i>Carex atlantica</i> | 17.1 | - |
| <i>Drosera rotundifolia</i> | 13.3 | 0.7 |
| <i>Osmunda cinnamomea</i> | 10.7 | 2.0 |
| <i>Carex trisperma</i> | 8.4 | 9.8 |
| <i>Carex exilis</i> | 8.0 | - |
| <i>Sarracenia purpurea</i> | 6.5 | - |
| <i>Carex collinsii</i> | 0.7 | 4.6 |
| <i>Juncus pelocarpus</i> | 4.2 | - |
| <i>Dulichium arundinaceum</i> | - | 2.6 |
| <i>Mitchella repens</i> | 0.7 | 2.6 |
| <i>Orontium aquaticum</i> | 2.1 | 0.7 |
| <i>Pogonia ophioglossoides</i> | 1.9 | - |
| <i>Carex folliculata</i> | - | 1.3 |
| <i>Peltandra virginica</i> | - | 0.7 |
| <i>Utricularia fibrosa</i> | 0.5 | - |
| <i>Drosera intermedia</i> | 0.4 | - |
| <i>Eriocaulon aquaticum</i> | 0.4 | - |
| <i>Eriophorum virginicum</i> | 0.2 | - |
| <i>Habenaria clavellata</i> | 0.2 | - |
| <i>Sparganium americanum</i> | 0.1 | - |
| Woody plants: | | |
| <i>Clethra alnifolia</i> | 11.1 | 37.3 |
| <i>Magnolia virginiana</i> | 2.4 | 30.7 |
| <i>Myrica pensylvanica</i> | 24.7 | - |
| <i>Rhododendron viscosum</i> | 10.6 | 18.3 |
| <i>Vaccinium corymbosum</i> | 10.9 | 16.3 |
| <i>Ilex laevigata</i> | 7.7 | 13.1 |
| <i>Chamaecyparis thyoides</i> | 5.5 | 11.1 |
| <i>Gaylussacia frondosa</i> | 8.2 | 10.5 |
| <i>Acer rubrum</i> | 3.9 | 9.8 |
| <i>Eubotrys racemosa</i> | 8.7 | 3.3 |
| <i>Kalmia angustifolia</i> | 5.5 | - |
| <i>Gaylussacia dumosa</i> | 4.1 | - |
| <i>Viburnum nudum</i> | 2.5 | - |
| <i>Vaccinium macrocarpon</i> | 2.4 | - |
| <i>Lyonia ligustrina</i> | 2.2 | - |
| <i>Aronia arbutifolia</i> | 1.9 | - |
| <i>Kalmia latifolia</i> | 0.9 | - |
| <i>Ilex glabra</i> | 0.6 | - |
| <i>Chamaedaphne calyculata</i> | 0.5 | - |
| <i>Gaultheria procumbens</i> | 0.5 | - |
| <i>Amelanchier canadensis</i> | 0.1 | - |
| <i>Ilex opaca</i> | 0.1 | - |
| <i>Quercus sp.</i> | 0.1 | - |
| <i>Rubus hispidus</i> | 0.1 | - |
| Herbaceous-species richness | 19 | 9 |
| Woody-species richness | 24 | 9 |
| Total-species richness | 43 | 18 |

individual cluster values ranging from -10 to 31 cm for Cooks and -3 to 38 cm for Shinns. Over 85% of all individual *Helonias* clusters at both sites were associated with 2-yr-median water levels ranging from 0 to 20 cm (Figure 1D). The median water levels associated with *Helonias* clusters were higher than the site-wide median water levels based on the transect points where no clusters were found, with a wider range of values associated with the latter (Figure 2).

At both Cooks and Shinns, more than 90% of the total *Helonias*-cluster area occurred at 2-yr median water levels between -5 and 19.9 cm, with the 5 to 9.9-cm water-level class supporting the greatest total *Helonias*-cluster area (Figure 4). Less than 10% of the total cluster area was associated with median water levels ≥ 20 cm from the base of the clusters at both sites. *Helonias* was absent where surface water was >5 cm above the base of the clusters at Shinns and >10 cm at Cooks. At the drier end of the hydrologic gradient, *Helonias* was absent where water levels were ≥ 35 cm below the base of the clusters at Cooks and ≥ 40 cm at Shinns. The percentage of *Helonias*-cluster area in each of the 5-cm water-level classes at Cooks and Shinns were correlated ($r = 0.85$, $p < 0.001$). The percentage of *Helonias*-cluster area and the percentage of transect points in each of the 5-cm water-level classes were correlated for Cooks ($r = 0.70$, $p < 0.001$) but not for Shinns ($r = 0.34$, $p = 0.064$). Based on total *Helonias*-cluster area, *Helonias* occupied a relatively narrow range of water levels compared to the range associated with transect points where *Helonias* was absent (Figure 4).

Simulated Water-reduction Impacts on *Helonias* and *Helonias* Habitat

At both sites, water-level reductions of 5 cm and 15 cm exposed $<10\%$ and $>30\%$ of the *Helonias*-cluster area to extreme hydrologic conditions (Figure 5), when extreme conditions were defined as the water level at which $<10\%$ *Helonias*-cluster area occurred (i.e., 20-cm water level for both sites). A 30-cm drawdown exposed the entire *Helonias*-cluster area at Cooks and 97% of the *Helonias* area at Shinns to extreme conditions in this scenario. When extreme hydrologic conditions were defined as the water level at which *Helonias* was absent (i.e., 35-cm water level at Cooks and 40-cm water

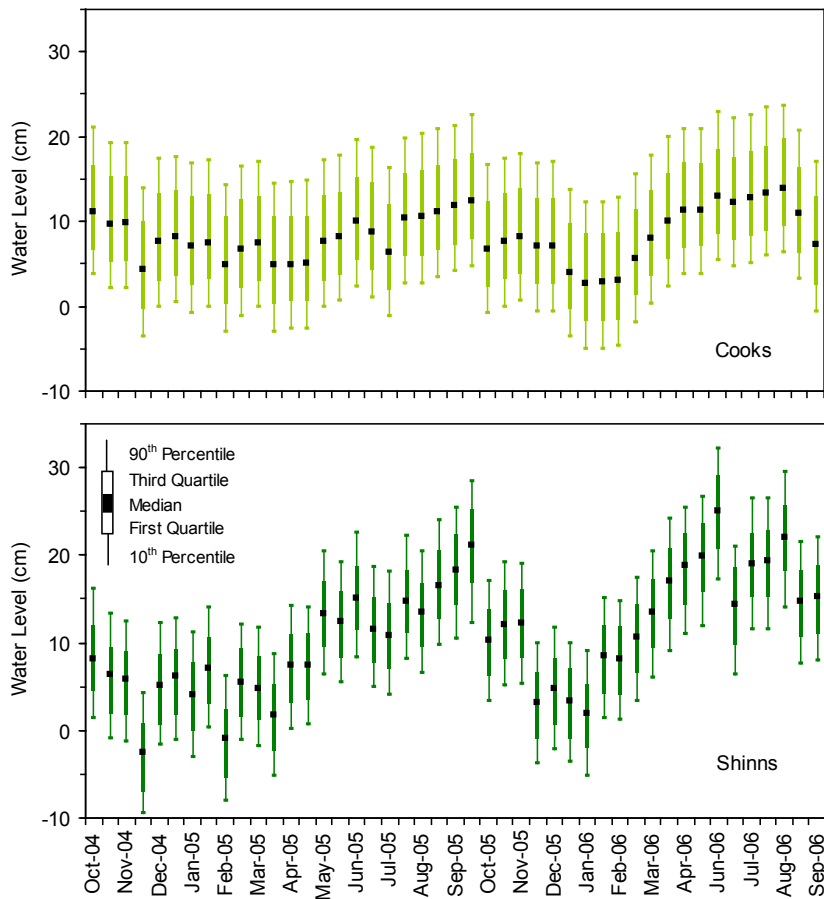


Figure 3. Water levels associated with *Helonias* clusters for Cooks (top $n = 805$) and Shinns (bottom $n = 153$) on individual water-level sampling dates for October 2004 – September 2006. Negative water-level values indicate submergence.

level at Shinns), negligible *Helonias*-cluster area was exposed to extreme conditions at simulated reductions of 15 cm or less. At both sites, a 45-cm drawdown exposed greater than 95% of the *Helonias*-cluster area to extreme conditions.

Under existing site conditions, 32% of Cooks and 28% of Shinns transect points occurred within the 10th and 90th percentile water levels associated with *Helonias* (Figure 6). No consistent trends in suitable habitat availability occurred for simulated drawdowns of up to 15 cm at Cooks and 40 cm at Shinns because as some transect points shifted beyond the range of water levels associated with *Helonias* (i.e., the points became too dry), other points that were previously deeply submerged under water entered the *Helonias* water-level range as the water level decreased. Drawdowns that exceeded these amounts corresponded to a steady decline

in suitable habitat. A 50-cm drawdown at Cooks and a 65-cm drawdown at Shinns resulted in the availability of less than 10% suitable *Helonias* habitat at both sites.

DISCUSSION

The herbaceous and woody species associated with *Helonias* clusters (Table 2) are typical of Pinelands *C. thyoides* swamps (Laidig and Zampella 1999) and are similar to those found at other *Helonias* sites in the Pinelands (Windisch 1992). Although the greater woody and herbaceous species richness at Cooks may reflect the larger number of *Helonias* clusters sampled at this site, average cluster-species richness was also higher than that recorded for Shinns. Higher light levels associated with lower tree canopy cover and fewer inundation

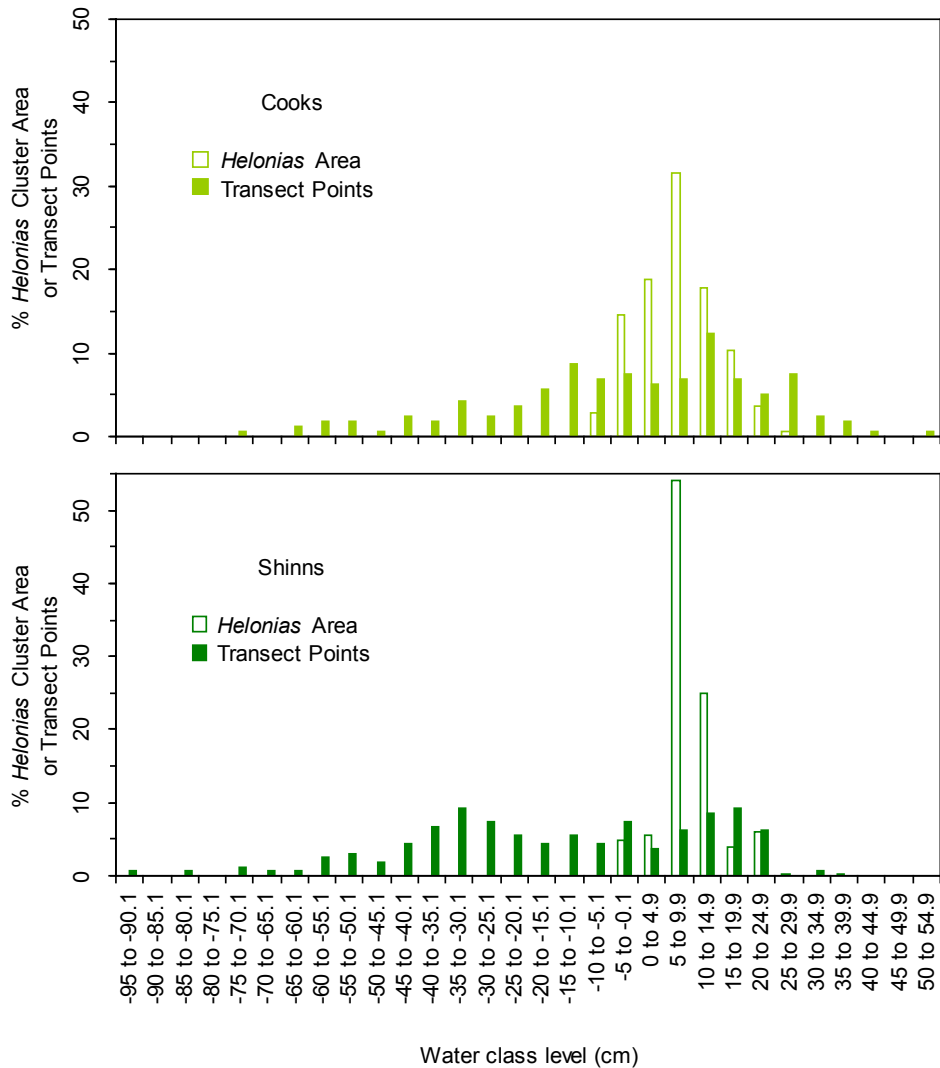


Figure 4. The percentage of total *Helonias* cluster area for Cooks (total area = 215,000 cm²) and Shinns (total area = 26,300 cm²) and the percentage of transect points where *Helonias* was absent (Cooks n = 161, Shinns n = 163) associated with 5-cm water-level classes. Negative water-level values indicate submergence.

events at Cooks may have contributed to the greater species richness at this site. These factors may also be associated with the higher *Sphagnum* frequency at Cooks.

More than 90% of the *Helonias*-cluster area was found at 2-yr median water levels between -5 and 19.9 cm and the largest proportion of cluster area was associated with water levels between 5 and 9.9 cm (Figure 4). The 2-yr water level ranges for Cooks (11.9 cm) and Shinns (27.9 cm) are relatively narrow compared to the ranges reported for Pinelands wetlands found on mineral hydric soils (Zampella et al. 1992, Zampella 1994), but similar to those reported

for *C. thyoides* swamps (Laidig and Zampella 1999). Although quantitative hydrologic data were not available for comparison, our observations are consistent with qualitative descriptions of hydrologic conditions associated with *Helonias* at other sites. Sutter (1982), for example, observed that only slight growing season water table fluctuations occurred at southern Appalachian *Helonias* sites, where water tables were “near the surface.” Likewise, Arsenault (1995) indicated that the hydrology of *Helonias* habitat in New Jersey was characterized by the presence of consistent water-saturated or standing-water conditions.

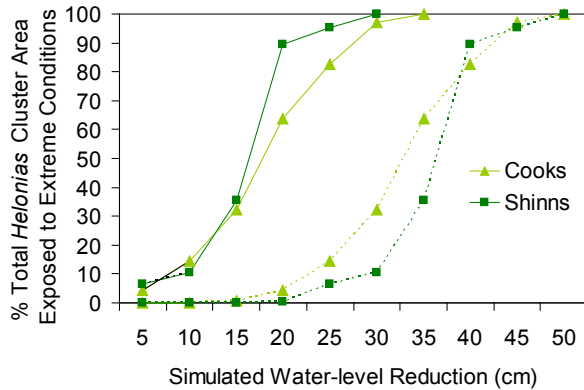


Figure 5. The estimated percentage of total *Helonias* cluster area exposed to extreme hydrologic conditions at various simulated water-level reductions. Extreme hydrologic conditions are defined in this study in two ways, including the median water level at the drier end of the hydrologic gradient beyond which <10% of the total existing *Helonias* cover occurred (i.e., 20-cm water level for both sites; solid lines) and the water level beyond which *Helonias* was absent (i.e., 35 and 40-cm water levels at Cooks and Shinns, respectively; dashed lines).

The pronounced difference in water levels associated with *Helonias* clusters and those associated with transect points where the plant was not present at Shinns, and to a lesser extent at Cooks (Figure 2), and the relatively narrow range of water levels associated with *Helonias*-cluster area (Figure 4) suggest that *Helonias* clusters were not uniformly distributed in relation to water level at the sites. *Helonias* was primarily associated with the upper, mostly emergent, portions of hummocks in and along the stream channel. The association of *Helonias* with hummocks and the stream channel has been noted for other *C. thyoides*-dominated study sites (Windisch 1992). Descriptions of *Helonias* at some hardwood-dominated sites (Windisch 1991, Arsenault 1995), however, suggest hardwood sites may exhibit a more variable distribution of plants with respect to proximity to a stream channel. The lower *Helonias* cover values associated with water levels closer to the surface at Shinns may be due to the more variable hydroperiod relative to Cooks, which leads to more frequent inundation of the lower parts of the hummocks. Although the effect of flooding on growth and vigor of *Helonias* was not examined in this study, some of the *Helonias*-clusters at our study sites were submerged for a period of time, indicating that *Helonias* can tolerate some flooding of the root zone. A pilot

study that explored the physiological effects of varying water levels on *Helonias* (Novy et al. 2007) indicated that, although increases in ethylene production and root-aerenchyma formation may have facilitated *Helonias* survival in waterlogged and submerged conditions, a twelve-day exposure to flooding stress was associated with leaf senescence and a twenty-day exposure to flooding stress was associated with reduced growth of roots and shoots.

The lower tree-canopy cover associated with the *Helonias* colonies relative to the adjacent forest (Table 1) indicates that canopy shading may influence within-site *Helonias* distribution. The dense evergreen canopy associated with *C. thyoides*-dominated sites may greatly reduce light availability except in the vicinity of the linear canopy gaps that are often associated with stream channels. At the other extreme, complete removal of the tree-canopy in *C. thyoides*-dominated sites by timber harvesting or wildfire has been associated with a reduction in *Helonias* seedling germination and survival due to changes in microhabitat (Windisch 1993). In contrast to the *C. thyoides*-dominated sites that we studied, the generally higher canopy cover (84 to 95%) measured at some hardwood-dominated *Helonias* sites (Peterson 1992) suggests that canopy shading may be less of a factor in the distribution of *Helonias* under hardwood canopies. The more diffuse tree canopy associated with hardwood species, especially evident in the early growing season prior to deciduous-tree leaf emergence and in the late growing season after leaf senescence,

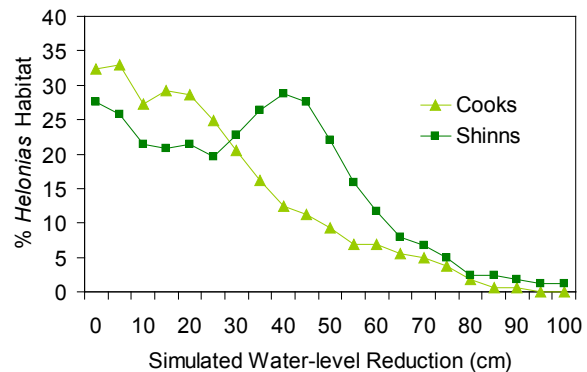


Figure 6. The estimated percentage of habitat that occurs within the 10th and 90th percentiles of measured water levels associated with *Helonias* at various simulated water-level reductions.

may allow for greater light availability to the evergreen rosettes of *Helonias*.

In addition to hydrology and canopy shading, other factors may contribute to the apparent limitation of *Helonias* to hummocks in and along the stream channel at *C. thyoides*-dominated sites. Windisch (1993) noted that, although wildfires may occasionally enter these wetlands, the rarity of root-killing fires in the water-saturated stream-bank zone may account for this stream-channel distribution pattern. The presence of extreme hummock/hollow topography, deep muck interspersed with pools of water, woody debris, and dense shrub cover associated with this zone may serve as an impediment to deer and thus reduce the *Helonias* herbivory that has been documented at other sites (Sutter 1984, Arsenault 1995, Johnson 1998). Various reproductive traits of *Helonias*, including low seed-germination rates, low seed-dispersal distances, low seedling establishment, the primary role that vegetative growth plays in the maintenance of colonies, and the relatively low occurrence of flowering rosettes as noted in this study and at other locations (Sutter 1982, 1984, Peterson 1992) may also influence *Helonias* distribution. Historic commercial collecting of *Helonias* flowers and whole plants (Brown 1910) and ongoing collecting in more recent times (U. S. Fish and Wildlife Service 1991) cannot be discounted as another factor that may have affected within-site distribution patterns.

Although we expressed the impact of simulated water-level reductions as the percentage of *Helonias*-cluster area exposed to extreme hydrologic conditions (Figure 5), determining actual impacts to *Helonias* plants would require additional study. In a greenhouse experiment, Dodds (1996b) evaluated the response of potted, mature *Helonias* plants over a one-year period to three water-level treatments, including a “low-water” treatment that allowed the soil to dry between additions of water. Dodds (1996b) recorded no differences in *Helonias* growth and reproduction in response to the treatments and concluded that the water-level conditions tested were within the short-term tolerance of *Helonias*. In a related experiment that evaluated survival of mature plants transplanted at two water-level positions (10 and 20 cm above surface water at the time of planting) at a wetland restoration site, Dodds (1996b) recorded no difference in *Helonias* survival between

the treatments. Because this second experiment examined the effects of growing *Helonias* at positions that were within the range of water levels associated with *Helonias* in our study and below the threshold that we defined as extreme conditions, the effects of experimental exposure to more extreme drawdown conditions remain to be examined. Studies of other wetland species may provide some indication of potential responses of *Helonias* to lowered water levels. For example, dewatering impacts associated with riparian cottonwoods (*Populus* spp.), a group of species that is dependant on the presence of shallow groundwater, include a range of drought-stress physiological responses, associated morphological changes, and in extreme cases, mortality (Rood et al. 2003).

The simulated water-level reduction scenarios indicated that, for minor drawdowns, habitat lost to extreme conditions may be countered by the dewatering of previously submerged substrate (Figure 6). Whether this dewatered habitat can compensate for the amount of *Helonias* exposed to extreme conditions depends on the potential for *Helonias* to become established in these dewatered areas through seedling establishment, vegetative growth, or physiological acclimation. Because seed-dispersal distance, seed-germination rates, and seedling establishment are reported as low in the field (Sutter 1982, 1984, Peterson 1992) and attempts to establish *Helonias* at a restoration site via direct seeding were unsuccessful (Dodds 1996b), the likelihood of *Helonias* seedling establishment occurring on dewatered substrate appears to be low. The influence of substrate type, moisture regime, the presence of *Sphagnum*, and other environmental factors on *Helonias* seed germination and seedling recruitment in the field has not been examined. Because *Helonias* can produce new rosettes via rhizomes and individual rosettes have been observed to spread 5 cm over a two-year period (Sutter 1984), colonization of dewatered substrate on the hummocks by vegetative growth may be more feasible. However, the steep, nearly vertical sides of many hummocks observed at our study sites and the timing and rate of water drawdown are factors that may affect such colonization potential. A more detailed examination of *Helonias* rosette distribution with respect to hummock microtopography as well as an assessment of the influence of environmental

parameters on the production of new rosettes and the direction, rate, and extent of rosette movement may provide a more solid basis on which to evaluate colonization potential of *Helonias* on dewatered substrate. Other factors, such as seasonal variation in the amount and duration of groundwater withdrawals could also affect the degree of hydrologic impact on *Helonias*. For example, greater withdrawals that occur during the driest time of the year may stress the plants at a time of maximal physiological activity.

Restoration of *Helonias* to sites where it has been extirpated and the establishment of new colonies are among the recovery strategies proposed for this species (U. S. Fish and Wildlife Service 1991). The *Helonias*-hydrologic relationships characterized in this study may facilitate the selection of candidate restoration sites that exhibit suitable hydrology and may aid in the identification of micro-site locations for the placement of transplanted *Helonias* individuals. With respect to proximity to water level and site hydrology, we consider the optimal location for *Helonias* to occur at a median value of 5 to 9.9 cm above the water surface at sites that exhibit low water-level variability. Our observations at *C. thyoides*-dominated sites also indicate that *Helonias* is associated with emergent portions of in-stream and stream-bank hummocks beneath a relatively open tree canopy. Results of the water-level drawdown simulations may be useful in assessing the potential for hydrologic impacts to *Helonias* colonies located near proposed water-supply or irrigation wells, adjacent land development, or stream impoundments.

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