VULNERABILITY AND COMPARABILITY OF NATURAL AND CREATED WETLANDS

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Cover: Blueberry Pond is a natural, 1.0 ha (2.4 ac), permanent-water pond located in Wharton State Forest in the New Jersey Pinelands. *Xyris smalliana* is the red-colored plant featured prominently in the foreground. Photograph taken by John F. Bunnell on September 25, 2013.

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Contents

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ABSTRACT

We identified and mapped 5,850 natural ponds, excavated ponds, and stormwater basins in the Pinelands Area. We assessed the vulnerability of natural and excavated ponds to developed land by simulating a buildout scenario and assessing changes in surrounding developed land, the percentage of non-native plant species, and pH for each pond. Natural ponds were less vulnerable than excavated ponds to future developed land because most natural ponds were located in protected areas of the Pinelands.

We also assessed off-road vehicle damage at natural and excavated ponds and found that ponds that were larger, with greater amounts of open water and herbaceous vegetation cover, near other damaged ponds, and closer to sand or paved roads tended to be damaged by off-road vehicles more often than smaller ponds with greater shrub and tree cover that were either located in developed or farmed landscapes or in less accessible and remote areas of the forest. A greater percentage of excavated ponds were damaged by off-road vehicles compared to natural ponds.

In a small subset of natural ponds, we explored whether or not dragonfly and damselfly species varied with surrounding land-use conditions. Our results showed that these species may be more influenced by forest canopy cover and wetland size rather than surrounding land use, but additional research is needed to fully determine if land use plays a major role in shaping the composition of these species groups in natural ponds or in other types of Pinelands wetlands.

Lastly, we compared 39 environmental and biological variables between natural ponds, excavated ponds, and stormwater basins. Our results showed that both natural and excavated ponds can exhibit high ecological integrity, display characteristic Pinelands water-quality conditions, and support native assemblages of plants and animals, whereas water-quality conditions in stormwater basins are degraded and basins are a major source of non-native and introduced species.

EXECUTIVE SUMMARY

Background

Coastal-plain ponds are a distinct feature in the New Jersey Pinelands. Because these wetlands are hydrologically connected to local groundwater sources, act as biogeochemical processing systems, and are necessary for the maintenance of regional plant and animal diversity, ponds serve important ecological functions. Groundwater pumping, water-quality degradation, off-road vehicles, and species invasions are among the primary threats to these vulnerable wetlands.

Like natural ponds, created wetlands can also provide important habitats for wetland-dependent plants and animals, especially in human-dominated landscapes where natural wetlands may have been altered or eliminated. Two types of created wetlands commonly found in the Pinelands are shallow excavations that intercept the groundwater (i.e., excavated ponds) and excavations designed to receive runoff (i.e., stormwater basins).

Although developed and agricultural land uses have been linked to water-quality degradation and the invasion of non-native plants and animals in Pinelands streams and impoundments, the vulnerability of natural and excavated ponds to surrounding land use or other human activities has not been well documented. Previous Pinelands Commission research indicated that some aspects of natural and excavated ponds were similar, but the ponds studied were located in protected forested landscapes and it remains unknown whether natural ponds are comparable to excavated ponds across a range of surrounding land-use conditions.

The Comprehensive Management Plan administered by the Pinelands Commission requires that stormwater generated by major developments be retained and infiltrated on the development site using methods that include stormwater basins. Stormwater basins have been shown to provide habitat for wetland plants and animals in the Pinelands and elsewhere, but it is not known how well basins function as wetlands compared to natural Pinelands ponds or other created wetlands in the region, such as excavated ponds.

EPA Funding

In 2012, the Pinelands Commission obtained EPA funding for a proposal titled, “Assessing the Ecological Integrity of Intermittent Ponds and their Vulnerability to Land-use Impacts (CD97208100).” The following year, the Commission received funding for a companion study that focused on excavated ponds and stormwater basins and was titled, “Comparing the Functional Equivalency of Natural and Created Wetlands (CD96294000).” Although funding was obtained during different years, field work for both studies was synchronized and all of the wetlands were monitored during the same period. The initial objectives from each study and the subsequent data analysis and results have been consolidated in this single report. As a component of the second study, scientists from the Commission and the U.S. Geological Survey (USGS) New Jersey Water Science Center collaborated to investigate differences in current-use pesticides and emerging-amphibian pathogens between a subset of natural ponds, excavated ponds, and stormwater basins. Results of that study are described in a separate USGS report (Smalling and others 2018).

Objectives

We accomplished five goals in these studies. We created an inventory of natural ponds, excavated ponds, and stormwater basins for the entire Pinelands Area; evaluated the vulnerability of natural and excavated ponds to surrounding land use; surveyed natural and excavated ponds for off-road vehicle damage; explored the relationship between land-use surrounding natural ponds and dragonflies and damselflies; and tested a series of biological and environmental metrics to assess the comparability of all three wetland types. In this report, we describe the species of plants and animals supported by each type of wetland, provide a measure of the potential vulnerability to certain human activities, and help advance the overall understanding of the comparability of wetlands in the region.

Summary of Major Findings

Wetland Inventory. We identified and mapped 5,850 wetlands in the Pinelands Area that included 2,742 natural ponds, 1,690 excavated ponds, and 1,418 stormwater basins. These 5,850 sites represent our natural pond, excavated pond, and stormwater basin (i.e., wetland) inventory. The Pinelands Area contains nine different management areas that govern the type, location, and intensity of land uses permitted throughout the region. Most natural ponds were located in the two most protective Commission management areas, the Forest Area and the Preservation Area District, and were typically surrounded by forested land with relatively low amounts of developed land and agriculture. Most excavated ponds were located in the Forest Area, Rural Development Area, and Agricultural Production Area, and were generally surrounded by intermediate amounts of developed and agricultural land. In contrast to natural and excavated ponds, almost 60% of the stormwater basins were located in the Regional Growth Area, and, as expected, most basins were surrounded by high-intensity developed land with a relatively low amount of agriculture.

Wetland Vulnerability at Buildout. We assessed the vulnerability of natural and excavated ponds to buildout conditions by simulating a scenario of maximum development in the four Commission management areas that were designed to receive the majority of development. An increase in the amount of developed land that surrounds a pond from 2012 to the future buildout scenario indicated an increase in vulnerability. About 79% of the natural ponds in the wetland inventory showed no change in vulnerability at buildout, whereas 21% showed an increase in vulnerability at buildout. This was due to most natural ponds being located in the two most ecologically protective management areas and fewer natural ponds being located in the four development-oriented areas. In contrast, about 55% of the excavated ponds in our inventory increased in vulnerability at buildout because excavated ponds outnumbered natural ponds in all but the two most protective management areas. Both types of ponds were most vulnerable to future development in the Rural Development Area.

We also simulated changes in the percentage of non-native plant species per pond and changes in pond pH between 2012 and the future buildout scenario. About 19% of natural ponds and 52% of excavated ponds showed a predicted increase in the percentage of non-native herbaceous plant species per pond at buildout. The estimated average percentage of non-native herbaceous plant species per pond nearly doubled in the Regional Growth Area, doubled in the Pinelands Town management area, and more than tripled for both the Pinelands Village management area and the Rural Development Area. In contrast to non-native plants, most natural and excavated ponds showed little predicted change in pH between 2012 and buildout. Results of these scenarios can be used to identify ponds that may be vulnerable to future developed land and show that excavated ponds are more vulnerable to current and potential future development compared to natural ponds.

Wetland Vulnerability to Off-road Vehicle Damage. Wetlands throughout the Pinelands have been damaged by off-road vehicles. We surveyed 3,585 natural and excavated ponds for off-road vehicle damage using 2007 aerial imagery and completed on-ground surveys at the remaining 847 ponds in 2013 – 2017. We used 2007 imagery because that was the most current imagery available when we initiated this study. For aerial and on-ground surveys together, we observed off-road vehicle damage at 195 ponds, including 84 natural ponds and 111 excavated ponds. Ponds that were larger, with greater amounts of open water and herbaceous vegetation cover, near other damaged ponds, and closer to sand or paved roads tended to be damaged by off-road vehicles more often than smaller ponds with greater shrub and tree cover that were either located in developed or farmed landscapes or in less accessible and remote areas of the forest. We found no link between approved enduro routes and off-road vehicle damage to ponds.

About 40% of all natural and excavated ponds identified as part of our inventory were located on state-owned land, which included New Jersey Department of Environmental Protection Division of Fish and Wildlife, Division of Parks and Forests, and Natural Lands Trust properties. The other 60% were owned by non-state entities, such as municipalities, non-governmental organizations, homeowners associations, and private landowners. The percentage of natural ponds that were damaged in each of the three state land management units was similar at about 4%, whereas the percentage of excavated ponds that were damaged on state land was greater overall and ranged from 16% on Fish and Wildlife land to 47% on Natural Lands Trust property. For non-state-owned land, the percentage of natural ponds with damage was 2% and the percentage of excavated ponds with damage was 4%. These results indicate that excavated ponds may be more vulnerable than natural ponds to off-road vehicle damage, especially on state-owned land.

Dragonfly and Damselfly Assemblages as Indicators of Land Use. In this pilot study, we explored whether or not dragonflies and damselflies in natural ponds varied with surrounding land-use conditions. A total of 59 species were found at the 33 natural ponds surveyed. Although our results showed that dragonfly and damselfly species in natural ponds may be more influenced by forest canopy cover and wetland size rather than surrounding land use, additional research is needed to fully determine if land use plays a major role in shaping the composition of odonate assemblages in natural ponds or in other types of Pinelands wetlands.

Comparability of Natural and Created Wetlands. From the larger wetland inventory, we selected 99 natural ponds, 52 excavated ponds, and 46 stormwater basins and sampled basic water chemistry, measured water levels, and surveyed plants, fish, and frogs and toads. We then tested 16 environmental and 23 biological variables among these 197 sites to assess the comparability of the three wetland types.

Although the amount of surrounding upland agriculture was similar for all three wetland types, stormwater basins were surrounded by a much greater amount of developed land compared to natural and excavated ponds. Natural ponds were located in the wettest landscapes, excavated ponds in the driest landscapes, and stormwater basins were surrounded by greater amounts of non-forest land. Specific conductance, which is a measure of dissolved substances in water, was low for natural and excavated ponds compared to stormwater basins. Water temperature was similar for all three wetland types. Natural ponds were the most acidic wetlands, excavated ponds were intermediate, but still quite acidic, and most stormwater basins were near neutral.

Natural ponds were generally larger than excavated ponds and stormwater basins. Excavated ponds were often deeper and dried less frequently than natural ponds and stormwater basins. Wetland water levels in natural and excavated ponds fluctuated more widely than the water levels in stormwater basins. Tree cover was highest and herbaceous cover lowest for natural and excavated ponds compared to stormwater basins. Shrub cover was greatest for natural ponds, intermediate for excavated ponds, and lowest for stormwater basins. Excavated ponds contained a greater amount of open water compared to natural ponds or stormwater basins.

We found 331 plant species, 14 frog and toad species, and 14 fish species at the 197 wetlands. We grouped species into Pine Barrens species (those found primarily in the Pinelands), wide-ranging species (those found throughout New Jersey, including the Pinelands), non-native species (those normally found in New Jersey, but outside the Pinelands), and introduced species (those that originated from other countries). The most striking difference between the three wetland types was the occurrence and dominance of non-native plants and animals in stormwater basins. In particular, introduced plant species only occurred in basins.

Of the 39 environmental and biological variables assessed between the three wetland types, twice as many variables differed between stormwater basins and ponds than differed between the two types of ponds, indicating that natural and excavated ponds are much more similar to each other than either wetland is to stormwater basins. Our results show that both natural and excavated ponds can exhibit high ecological integrity, display characteristic Pinelands water-quality conditions, and support native assemblages of plants and animals. In contrast, water-quality conditions in stormwater basins are degraded and these wetlands are a source for non-native and introduced species.

Introduction

Geographically isolated wetlands can be found in low topographic areas throughout much of the United States (Tiner 2003). Along the Atlantic Coast, these wetlands, known regionally as Carolina bays, pocosins, Delmarva potholes, coastal-plain ponds, and vernal pools (Tiner 2003), serve important ecological functions because they are hydrologically connected to local groundwater sources, active biogeochemical processing systems, and maintain regional biodiversity by providing habitat for wetland-dependent plants and animals (Leibowitz 2003, Marton and others 2015, Cohen and others 2016).

Coastal-plain ponds are a distinct feature in the New Jersey Pinelands that, until recently, have received little investigation relative to other Pinelands ecological communities. Similar to other types of isolated wetlands, coastal-plain ponds are discrete water bodies not typically fed by streams that exhibit a range of hydrologic permanence, support wetland plant and animal assemblages, and often contain rare species (Bunnell and Zampella 1999, Zampella and Laidig 2003, Bunnell and Ciraolo 2010, Laidig 2012). Groundwater pumping, water-quality degradation, off-road vehicles, and species invasions are among the primary threats to these vulnerable wetlands (Tiner 2003).

Like coastal-plain ponds, created wetlands can also be geographically isolated and represent important habitats for wetland-dependent plants and animals (Tiner 2003), especially in human-dominated landscapes where natural wetlands may have been degraded or eliminated. Two types of created wetlands commonly found in the Pinelands are shallow excavations that intercept the groundwater (i.e., excavated ponds) and excavations designed to receive runoff (i.e., stormwater basins).

Based on two previous Pinelands studies, the hydrology, vegetation composition, and anuran (frog and toad) assemblages of natural and excavated ponds were found to be relatively similar (Bunnell and Zampella 1999, Zampella and Laidig 2003). However, because these ponds were located in protected forested landscapes, it is unknown whether excavated ponds are comparable to natural ponds across a range of surrounding land-use conditions. Although developed and agricultural land uses have been linked to water-quality degradation and the invasion of non-native plants and animals in Pinelands streams and impoundments (Zampella and Laidig 1997, Zampella and Bunnell 1998, Dow and Zampella 2000, Zampella and Bunnell 2000, Zampella and others 2007, Bunnell and Zampella 2008), the vulnerability of natural and excavated ponds to surrounding land use or other human activities has not been well documented.

The Comprehensive Management Plan administered by the Pinelands Commission requires that stormwater generated by major developments be retained and infiltrated on the development site using methods that include stormwater basins (Pinelands Commission 1980). Stormwater basins have been shown to provide habitat for wetland vegetation, fish, and amphibians in developed landscapes in the Pinelands (McCarthy and Lathrop 2011) and other areas of the United States (Baschietto and Adams 1983, Ostergaard and others 2008, Simon and others 2009). However, little is known about how well stormwater basins function as wetlands compared to natural Pinelands ponds or other created wetlands in the region, such as excavated ponds.

In this study, we created a wetland inventory of natural ponds, excavated ponds, and stormwater basins for the entire Pinelands Area. Using this inventory, we evaluated the vulnerability of natural and excavated ponds to surrounding land use and off-road vehicle damage; explored the relationship between land-use surrounding natural ponds and dragonfly and damselfly assemblages; and tested a series of biotic and abiotic metrics to assess the comparability of all three wetland types. In this report, we describe the species of plants and animals supported by these wetlands, provide a measure of the potential vulnerability to certain human activities, and help advance the overall understanding of the comparability of wetlands in the region.

METHODS

Study Area

The Pinelands Area is a 379,000 ha (938,000 ac) region within the slightly larger Pinelands National Reserve that is located on the outer coastal plain of southern New Jersey (Figure 1). About 82% of the Pinelands is composed of forest, wetlands, and water and the remaining 18% is farmed and developed (Zampella et al. 2008). The surficial Kirkwood-Cohansey aquifer system underlies the region (Walker and others 2011) and supports wetland types that range from open-water ponds and streams to densely forested Atlantic white cedar (*Chamaecyparis thyoides*) and red maple (*Acer rubrum*) swamps and drier pitch pine (*Pinus rigida*) lowlands (McCormick 1979). Hydrology is the primary factor that influences the wetlands types and wetland-dependent plants and animals of the region (Zampella and others 1992, Bunnell and Ciraolo 2010, Laidig and others 2009, Laidig 2012, Laidig and others 2010). Pinelands soils generally consist of sands and gravels with discontinuous clay layers that may influence groundwater movements (Walker and others 2008).

Wetland Inventory

Wetland Mapping. Using ArcMap (Environmental Systems Research Institute, ESRI, Inc., Redlands, CA) and 2007 leaf-off infrared digital aerial imagery, we identified and delineated the perimeter of natural open-water and herbaceous ponds, excavated ponds no larger than the largest natural pond identified, and stormwater basins throughout the entire Pinelands Area. These mapped wetlands represented our wetland inventory. We used the delineated perimeter to determine wetland area and to visually estimate wetland structure, or the percentage of tree, shrub, herb, and water cover within the perimeter. We used the 2007 aerial imagery because this was the most current imagery available when we started mapping. To assist with the mapping, we also used digital aerial imagery from various years going back to the 1930's available on bing.com and historicaerials.com.

The wetlands we mapped were isolated in the sense that they were discrete water bodies separated from other water bodies by land and were not fed by streams. We avoided mapping

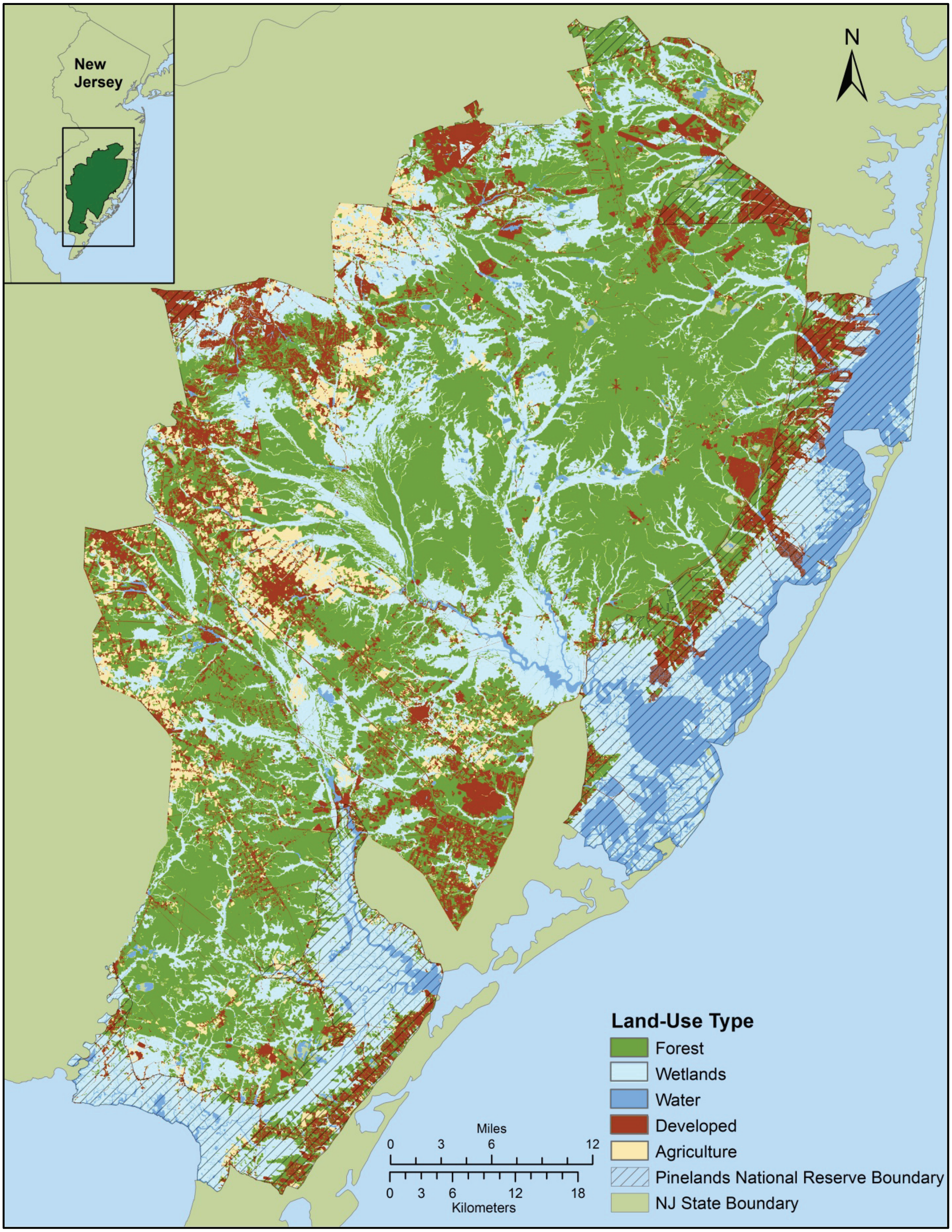

Figure 1. New Jersey Department of Environmental Protection 2007 land-use data (NJDEP 2010) and the Pinelands Area and Pinelands National Reserve in New Jersey.

water-filled depressions in closed-canopy swamps; shrub-covered wetlands with no visible open water; extensive, interconnected, or braided herbaceous and shrub-dominated wetlands; on-stream impoundments; other wetlands that were obviously connected to streams; large flooded sand and gravel mines; flooded craters on military land created by practice bombing; and narrow linear roadside stormwater basins.

Wetland Inventory and Pinelands Management Areas. The Pinelands Comprehensive Management Plan established nine management areas that govern the type, location, and intensity of land uses permitted throughout the Pinelands (Figure 2, Pinelands Commission 1980). In order of increasing ecological integrity (Zampella and others 2008), the nine management areas are Pinelands Town, Agricultural Production Area, Regional Growth Area, Pinelands Village, Rural Development Area, Federal or Military Facility, Forest Area, Special Agricultural Area, and Preservation Area District. Using ArcMap and the perimeter we delineated for each wetland, we determined the Pinelands management area in which each wetland was located and calculated the total number of each wetland type in the nine management areas. Because some ponds spanned more than one management area, we assigned each pond the dominant management area within the perimeter of a pond.

Wetland Inventory and NJDEP Land-use Data. The New Jersey Department of Environmental Protection (NJDEP) periodically updates its detailed land-use/land-cover maps for the entire state. These digital maps contain human land uses as well as natural habitats, including wetlands. To determine whether or not natural ponds, excavated ponds, and stormwater basins from our mapped inventory were also mapped as some type of wetland in the NJDEP land-use data, we used ArcMap and the 2007 land-use data (NJDEP 2007 Land-use/Land-cover Data Update, 2010) to summarize the various land uses within each wetland perimeter that we delineated. If the perimeter of our inventory wetlands did not include any NJDEP wetland types, then we considered our wetlands to not be mapped as a wetland in the NJDEP land-use data.

Study Site Selection

From the full inventory of wetlands that we mapped, we selected 99 natural ponds, 52 excavated ponds, and 46 stormwater basins for a total of 197 study sites (Table 1). Sites were chosen based on the history of use in previous Commission studies, the surrounding landscape to obtain a range of land-use conditions, accessibility from roads or trails, and land-owner permission to access sites. All sites were visited prior to selection. For the excavated ponds and stormwater basins, we used aerial photographs from historicaerials.com to determine the year when each of these created wetlands was first visible, which indicates the minimum age of these wetlands. As described in the following sections, these study sites were used to assess pond vulnerability at buildout, survey for off-road vehicle damage, explore the use of dragonfly and damselfly (odonate) assemblages as indicators of land use, and compare natural and created wetlands.

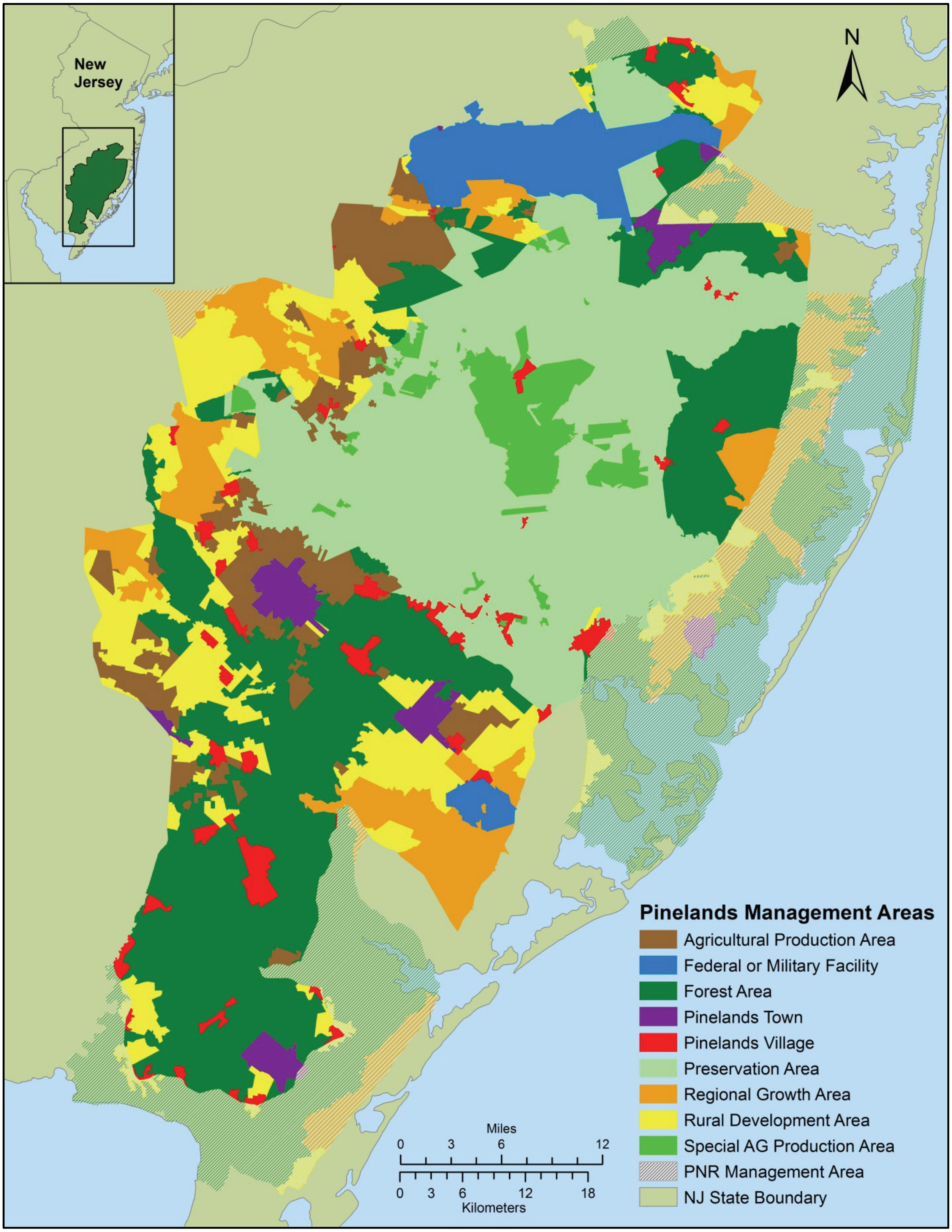

Figure 2. Pinelands Management Area designations in the Pinelands Area and Pinelands National Reserve.

Table 1. The number of natural pond, excavated pond, and stormwater basin study sites and the number of each surveyed for various attributes on different years. Water level and water quality were measured at the 197 sites during each of the three years.

Site Type	Vegetation	Adult Anurans	Larval Anurans	Fish	Odonates
Natural Ponds (N = 99)					
2014	53	53	16	6	17
2015	24	24	9	6	16
2016	22	22	7	2	-
Excavated Ponds (N = 52)					
2014	24	24	16	7	-
2015	14	14	9	4	-
2016	14	14	8	4	-
Stormwater Basins (N = 46)					
2014	26	26	9	5	-
2015	20	20	7	2	-
2016	0	0	2	0	-
Total Number of Sites	197	197	31	36	33

Wetland Vulnerability at Buildout

Buildout Scenario. We assessed the vulnerability of all natural and excavated ponds in the wetland inventory to future development by evaluating changes in surrounding developed land for ponds between 2012 and a hypothetical buildout scenario. To accomplish this, we used ArcMap, the natural and excavated ponds from our wetland inventory, 2012 land-use data (NJDEP 2012 Land-use/Land-cover Data Update, 2015), and two GIS layers maintained by the Commission: a permanently protected land layer (Pinelands Commission, January 2018 update) and the Pinelands Management Areas layer (Pinelands Commission, September 2017 update). In the Pinelands, most development is directed into four management areas: Pinelands Towns, Pinelands Villages, Regional Growth Areas, and Rural Development Areas.

To create the future buildout scenario, we used the 2012 land-use data to designate land within the four development areas that was unable to be developed and then converted buildable land in these areas to developed land. Land unable to be developed included state-owned lands, non-governmental organization preserves, land that was deed-restricted from development through various means, wetlands and water, and land within regulatory buffers to wetlands and water. We applied a 300-ft (91.4 m) upland buffer to all wetlands and water included in the 2012 land-use data, as well as to the perimeter of the natural and excavated ponds that we mapped, because this is the maximum buffer distance typically used to protect wetlands in the Pinelands (Pinelands Commission 1980). We did not include agricultural land as land that could be developed because of the unpredictability of future development on agricultural land. All other land in the four development areas was considered buildable and was converted to developed land for our buildout scenario.

We determined the amount of developed land surrounding each natural and excavated pond for 2012 and at buildout using a 500-m-radius polygon around the perimeter of each pond. Ponds that experienced an increase in developed land between the two periods were considered to become more vulnerable. We used the 2012 land-use data for this analysis because it was the most current land-use data available when we completed the analysis. To determine if a smaller distance from the perimeter would affect the results of this analysis, we also completed the same analysis using a 250-m-radius distance. For both analyses, a portion of the surrounding areas for 40 ponds fell outside the Pinelands jurisdictional boundary; therefore, those portions were excluded from the calculations for those ponds.

Buildout and Pinelands Management Areas. To assess the buildout results within individual Pinelands Management Areas, we used ArcMap, the management area layer, and our natural and excavated pond perimeters to determine the dominant management area where each pond was located. We summarized the number of ponds that increased in surrounding developed land between 2012 and buildout to determine in which management areas ponds increased in vulnerability.

Modeling Non-native Plants and Pond pH at Buildout. Previous studies in Pinelands streams and impoundments have shown that the percentage of non-native plants and pH can increase with the amount of developed land and upland agriculture in a watershed (Zampella and others 2006, 2010). To better understand the possible impacts of buildout on ponds, we generated predictive models to estimate potential changes in pH and the percentage of non-native herbaceous plants in ponds between 2012 and buildout. We constructed models using split-half cross validation with stratification. This technique randomly subsamples a stratified dataset to divide the sites into two mutually exclusive datasets that both represent the entire dataset (Kohavi 1995). We stratified the 151 natural and excavated study ponds (see Study Pond section above) by placing the ponds into groups according to the percentage of altered land (developed land + upland agriculture) within a 500-m-radius around each pond. To ensure the two datasets contained ponds with similar land-use distributions, the groups we created were 0%, 0.1-4.9%, 5.0-9.9%, 10.0-19.9%, 20.0-29.9%, 30.0-33.9%, 34.0-39.9%, 40.0-49.9%, 50.0-59.9%, and 60.0-86.0% altered land. We randomly selected ponds from each altered-land group to place into two separate datasets (Altered model 1 and Altered model 2). We also stratified the ponds into groups based on the percentage of non-native herbaceous plant species at a pond and generated two separate datasets (Plant model 1 and Plant model 2). The plant groups were 0%, 1.0-4.9%, 5.0-9.9%, 10.0-19.9%, 20.0-29.9%, 30.0-39.9%, and 40.0-100% non-native herbaceous species per site.

For each of the four datasets, we generated individual linear and quadratic models by regressing the percentage of altered land against the percentage of non-native herbaceous species. In split-half cross validation, model 1 data are tested on the model 2 data and vice-versa (Kohavi 1995). We evaluated the performance of the eight models (four linear and four quadratic) by comparing the Akaike information criterion, Bayesian information criterion, residual sum of squares, the model R-squared, and the observed versus predicted R-squared and selected the best model that met the assumptions of normality and homoscedasticity. One of the quadratic models was selected as the best model. We then applied the selected quadratic model to the remaining 4,281 natural and excavated ponds in the full inventory to predict the percentage of non-native herbaceous plants at each pond in 2012 and at buildout. If the estimated percentage of non-native plants was predicted to be greater than 100%, we converted these values to 100%. We evaluated changes in the predicted percentage of non-native herbaceous plants between 2012 and buildout.

We used a similar procedure to create the pH models. We used the same altered land groups as above and also stratified the ponds into groups based on pH to generate two datasets (pH model 1 and pH model 1). To ensure the two datasets contained ponds with similar pH distributions, the pH groups were 3.62-4.10, 4.11-4.19, 4.20-4.49, 4.50-4.99, 5.01-5.79, and 6.15-6.63. We generated four linear models by regressing the percentage of altered land against pH and evaluated the models using the same criteria listed previously. We then applied the selected model to the remaining 4,281 natural and excavated ponds in the full inventory to predict the pH of each pond in 2012 and at buildout. We evaluated changes in the predicted pH between 2012 and buildout.

Wetland Vulnerability to Off-road Vehicle Damage

In the early 1990's, Commission scientists began studying frog and toad and vegetation assemblages in natural and excavated ponds. Water levels at many of these ponds are now routinely measured as part of the Commission Long-term Environmental-monitoring Program. Off-road vehicle damage has occurred over the years at some of these long-term monitoring ponds, with a total of 13 of the 44 ponds, or 30%, being driven in by vehicles to date. In early 2017, NJDEP Division of Parks and Forests staff and a group of volunteers installed wooden guard rails across vehicle access points at some of the long-term monitoring ponds and other ponds that were heavily damaged by large vehicles (http://www.nj.gov/dep/newsrel/2017/17_0013.htm).

Off-road Vehicle Damage Surveys. Because damage to natural habitats by off-road vehicles appears to be an increasing problem in the Pinelands, as well as other areas of the United States (Wuerthner 2007), we surveyed all of the natural and excavated ponds in our wetland inventory for off-road vehicle damage using either aerial or on-ground survey methods. For the aerial methods, we used 2007 imagery to visually assess each pond for any evidence of off-road vehicle damage. On-ground surveys were completed from 2013 – 2017 during field work associated with these two studies.

Also in 2017, Commission, NJDEP, and Pinelands Preservation Alliance staff and volunteers collaborated to complete additional on-ground surveys at a number of ponds located on state land. We focused on state land to facilitate access. For all of the on-ground surveys, if we observed that vehicles had driven in a wetland, we noted the number of vehicle access points, type of vehicle tracks (motorcycle, all-terrain vehicle or quad, or truck), if the damage was minimal or extensive, and if the wetland was in need of immediate protection because of damage or easy vehicular access. We also recorded the presence of nearby piles of debris, trash, or yard waste; evidence of the site being a spot where people congregated to party; and the presence of stormwater pipes, ditches, or plow lines from the creation of fire breaks.

State-owned vs. Non-state-owned Land. We summarized the number of ponds that were damaged by off-road vehicles on state-owned and non-state-owned land. State-owned land included NJDEP Division of Fish and Wildlife wildlife management areas, Division of Parks and Forests state park and state forest land, and Natural Lands Trust preserves. Non-state-owned land included land owned by individual members of the public, non-governmental organizations, municipalities, and homeowner associations. Using ArcMap, the natural and excavated pond point locations from the wetland inventory, and the Commission permanently protected land layer, we determined whether ponds were located on state-owned or non-state-owned land, and summarized the number of ponds damaged for each type of land.

Off-road Vehicle Damage Model. We developed a model to assess the vulnerability of natural and excavated ponds to off-road vehicle damage in the Pinelands. To apply the model across the entire Pinelands, we modeled 10 variables that were available for each wetland in our natural and excavated pond inventory. The 10 variables were pond area; the percentages of surrounding developed land and upland agriculture; the percentages of tree, shrub, herb, and water cover; and the distance to the nearest damaged pond, road, and enduro route.

To obtain the three distance measures, we used ArcMap, the natural and excavated ponds in our wetland inventory, data for which ponds showed vehicle damage from the aerial and on-ground surveys, a GIS layer of improved and unimproved roads (CRSSA 2011), and a GIS layer of enduro routes from cross-country motorcycle events. The enduro route layer was created from individual routes submitted to the Commission for approval of enduro events since 2012.

To create a balanced model, we randomly selected ponds with no evidence of vehicle damage to equal the number of ponds where we observed vehicle damage, and used logistic regression to assess the relationship between the presence of damage at a pond and the 10 variables. To ensure that randomly selected ponds were representative of the entire dataset of undamaged ponds, we generated five logistic regression models using five different, randomly selected sets of undamaged ponds. In all five models, the same five variables were significantly related to vehicle damage, so we compared the five models using only those five variables. We compared the ratio of the null deviance to the residual deviance and evaluated the Akaike information criteria to assess differences in model performance and selected the best model.

Dragonfly and Damselfly Assemblages as Indicators of Land Use

Dragonfly and Damselfly Surveys. In our initial proposal to study natural ponds, we planned to explore whether odonate assemblages (dragonflies and damselflies) varied with surrounding land-use conditions. For this pilot study, we selected 33 of the 99 natural ponds that represented a range of surrounding land use and conducted monthly exuviae and adult surveys from May - September at each pond in 2014 - 2015 (Table 1). Exuviae are the exoskeletal remains from larval odonates when they shed their skin to become adults (Figure 3). Most often exuviae are left clinging to plants, logs, or the shoreline in areas above water.

We established three 1-m wide parallel transects perpendicular to the long axis of each pond that passed through the open water portion of the pond. All exuviae observed along the transects were collected for identification. Adults were identified and counted while walking along each transect and around the pond shoreline. We counted the number of adults present up to 10 individuals and grouped more abundant species into two categories (11-20 and >21 individuals).

Figure 3. Exuvia, or exoskeleton, left behind after a larval dragonfly molted and metamorphosed into an adult. Photograph is from Goldenclub Pond on August 2015 by John F. Bunnell.

Photographs of most adult species were collected at each pond using a Canon Rebel EOS digital SLR camera equipped with a Canon 70-300-mm zoom lens. Field and photograph identifications of adults were made using Dunkle (2000), Barlow and others (2009), and Paulson (2011). Exuviae were identified by NJDEP Bureau of Freshwater and Biological Monitoring staff using Westfall and others (2006) and Needham and others (2014).

Dragonfly and Damselfly Assemblages. We used detrended correspondence analysis (DCA, Hill, 1979; Hill and Gauch, 1980) to produce an ordination using odonate presence-absence data. DCA generates a single score for each site that incorporates the species information from a site and a single species score that represents the centroid of the species information from a dataset. The first-axis site scores and species scores of a DCA ordination summarize the majority of the variation in species data and represent the primary odonate-assemblage gradient (Zampella and Bunnell 1998, Bunnell and Zampella 1999, Zampella and others 2006).

We completed an ordination using presence-absence data for all adult odonates and exuviae combined. We used Spearman rank correlation to explore the relationship between odonate assemblage composition represented by the first-axis site scores of the ordination and developed land, specific conductance, pH, frequency of drying, pond area, tree-canopy cover, and species richness. Because of the exploratory nature of the odonate analysis, we also completed three other ordinations using presence-absence data that included dragonfly adults and exuviae, damselfly adults and exuviae, and adult dragonflies and damselflies with no exuviae. To determine if these other three ordinations showed the same pattern as the initial combined ordination, we compared the first-axis site scores of the combined ordination to the other three ordinations using Spearman rank correlation.

Using a classification system and methodology developed for Rhode Island wetlands (Kutcher and Bried 2014), we assigned a conservation score to each odonate species, where values range from 0 (association with highly degraded wetlands) to 10 (association with least disturbed conditions). We calculated a site conservation score by taking an average of the conservation scores for all the species present at a pond. To determine if the combined ordination was related to the above degradation classification, we used Spearman rank correlation to evaluate the relationship between species and site conservation scores and the first-axis species and site ordination scores.

Comparability of Natural and Created Wetlands

We used the 197 study sites selected from the larger wetland inventory and a series of abiotic and biotic attributes to assess the comparability of the natural ponds, excavated ponds, and stormwater basins. The attributes we compared are grouped into the following functional categories. This assessment is augmented by the companion U.S. Geological Survey study, where current-use pesticides and amphibian pathogens were compared among the three wetland types (Smalling and others 2018).

Landscape Setting. The landscape setting and habitat structure of a wetland can influence factors, such as water temperature, hydrologic permanence, nutrient inputs, leaf litter contributions, and species composition (Mitsch and Gosselink 2000, Colburn 2004). We used surrounding land use, surrounding forest hydrology, and wetland habitat structure attributes as landscape setting metrics for each wetland.

Surrounding Land Use. Using ArcMap, the NJDEP 2012 land-use data described above, and the wetland perimeters we generated, we determined the percentage of developed land and upland agriculture within a 500-m-radius polygon surrounding each wetland. These two upland land uses have been linked to alterations in water quality and the invasion of non-native plants and animals in Pinelands streams and impoundments (Zampella 1994, Dow and Zampella 2000, Zampella and others 2007, Zampella and Laidig 1997, Zampella and Bunnell 1998, Bunnell and Zampella 2008).

Surrounding Forest Hydrology. To characterize the hydrology of the forest immediately adjacent to each wetland, we used ArcMap, the 2012 NJDEP land-use data, and our wetland perimeters to determine the percentage of surrounding upland forest, wetland forest, and non-forest within a 25-m-radius polygon surrounding each wetland.

Wetland Habitat Structure. As described in the Wetland Inventory section previously, we used our wetland perimeters to determine wetland area and to visually estimate the percentage of tree, shrub, herb, and water cover within the perimeter. The cover estimates provided a measure of wetland habitat structure for each site. We used the 2007 imagery because it was the same imagery we used to map the wetlands.

Wetland Hydrology. Hydrology is a key factor that influences wetland function by driving biogeochemical processes and shaping the plant and animal assemblages that a wetland supports (Mitsch and Gosselink 2000). Frequency of drying, mean water depth, and mean water-depth fluctuation represented our hydrologic metrics.

We visited all 197 wetlands monthly from April – September in 2014 – 2016 to measure water depth in the deepest portion of each wetland that was accessible by wading (N = 18 visits for each site). We used the number of visits that a wetland was dry to determine the frequency of drying. We also determined the maximum annual water depth and annual range in water depth for each of the three years, and calculated mean water depth (N = 3) and mean water-depth fluctuation (N = 3). Eighteen wetlands were too deep to wade to the deepest part for a depth measurement so data were collected at more accessible locations. We applied the greatest mean water depth value from the 179 wadeable wetlands to the 18 wetlands that were too deep to measure the maximum depth.

Water Quality. We used pH, specific conductance, and water temperature as our water-quality metrics. Specific conductance and pH are easily measured field parameters that are related to the percentage of upstream developed land and upland agriculture in Pinelands streams and impoundments (Zampella 1994, Dow and Zampella 2000, Zampella et al. 2007) and subsequent invasions of non-native plants and animals in these habitats (Zampella and Laidig 1997, Zampella and Bunnell 1998, Bunnell and Zampella 2008). In the Pinelands, the relationship between these parameters and land use surrounding geographically isolated wetlands, such as natural ponds, excavated ponds, and stormwater basins, has not yet been quantified.

We measured pH, specific conductance, and water temperature in each wetland in April and May of 2014 – 2016. At the same location where we collected water depth measurements, we collected a water sample from 10 cm below the surface and used Orion 3-star meters to measure pH, specific conductance, and water temperature.

Plant and Animal Assemblages. The maintenance of plant and animal assemblages that are characteristic of wetlands from a region represents an important habitat and ecosystem integrity function (Smith and others 1995). We used vegetation, anuran (frog and toad), tadpole, and fish assemblages and various biogeographic species groups for each taxa as our integrity attributes. In previous Commission studies, similar taxa and species groups have been successfully used to assess the integrity of streams and impoundments (Zampella and Laidig 1997, Zampella and Bunnell 1998, Zampella and others 2006, Bunnell and Zampella 2008).

Unlike the hydrology and water-quality monitoring that occurred at all 197 sites during all three years, the plant and animal surveys were conducted at each wetland during a single year. For convenience, we divided the 197 sites into three groups based on their location in the region, and surveyed a different group of sites each year. Therefore, the number of natural ponds, excavated ponds, and stormwater basins surveyed during any year varied (Table 1).

Vegetation Surveys. To characterize the vegetation assemblage at each wetland, we visited each of the 197 wetlands once in June-July and once in September-October during a single year in 2014 – 2016 (Table 1). During each visit, we identified all woody and herbaceous plant species present within the wetland and identified the dominant herbaceous species (including *Sphagnum*).

Anuran Surveys. For the anuran species found in the Pinelands, mature males produce a distinctive advertisement call to attract females for mating. We conducted anuran vocalization surveys at the 197 wetlands to document which species of anurans were attempting to breed at each site. Daytime vocalization surveys were completed in late-February or early March and nighttime surveys were conducted monthly from March – June. Each wetland was surveyed on 4 – 8 occasions during a single year from 2014 – 2016. Repeat visits were made in early spring to ensure we heard species that breed early and for a short period of time, such as wood frogs (*Lithobates sylvaticus*) and New Jersey chorus frogs (*Pseudacris kalmi*). During each visit, we counted the number of vocalizing individuals of each species heard during a five-minute period up to 10 individuals. For more abundant species, we simply recorded the number 11.

Tadpole Surveys. For each wetland where we heard bullfrogs calling, we sampled for bullfrog larvae to determine whether or not they were successfully producing tadpoles (Table 1). Bullfrogs are not native to the Pinelands (Conant 1979), but can be found in on-stream Pinelands impoundments where water-quality has been degraded from development or upland agriculture (Zampella and Bunnell 2000, Zampella et al. 2006, Bunnell and Zampella 2008). We spent from 5 to 30 minutes sampling for bullfrog tadpoles using a 38 x 38-cm dip net (4.8 mm mesh size), a 2.4 x 1.2 m seine (4.0 mm mesh size), or a combination of both. We identified all other species of tadpoles that were found during the sampling and also identified all tadpoles collected during the fish surveys described below.

Fish Surveys. We completed fish surveys in 36 wetlands, including 14 natural ponds, 15 excavated ponds, and seven stormwater basins (Table 1). Based on the water depth and the amount of vegetation present in the wetlands, we spent from 10 to 30 minutes sampling fish at 33 of the 36 wetlands using a 38 x 38-cm dip net (4.8 mm mesh size), 2.4 x 1.2 m seine (4.0 mm mesh size, 2.1 m diameter cast net (9.5 mm mesh size), or a combination of methods. The remaining three sites were sampled using a dip net or seine from only one to seven minutes because so little water was present in the wetlands at the time of sampling.

Biogeographic Species Groups. We used previous classifications for plants (Stone 1911, Gleason and Cronquist 1991), anurans (Conant 1979), and fish (Hastings 1979, 1984) to categorize species into biogeographic groups. We refer to plant, fish, and anuran species whose distribution is generally limited to the Pinelands as Pine Barrens species, species that are native to both the Pinelands and other areas of New Jersey as wide-ranging species, and species that are native to regions of the United States outside the Pinelands as non-native species. For plants only, we refer to species originating outside the United States as introduced (USDA, NRCS 2018). Taxonomic nomenclature follows USDA, NRCS (2018) for plants, Collins (1997) for anurans, and Fuller and others (1999) for fish.

Data Analysis. To compare natural ponds, excavated ponds, and stormwater basins, we used analysis of variance (ANOVA) to test the abiotic variables described in the above functional categories between wetland types. Although ANOVA is generally robust to deviations from normality and heteroscedasticity, it is sensitive to heteroscedasticity in unbalanced designs such as ours (N = 99, 52, and 46 for natural ponds, excavated ponds, and stormwater basins, respectively). Therefore, we used Levine's test to evaluate heteroscedasticity among the wetland types and applied a Welch's correction (Welch 1951) to the ANOVAs for those attributes with unequal variances. We used the Games-Howell post-hoc test (Games and Howell 1976) to compare the abiotic variables between wetland types.

To compare entire plant and animal assemblages between natural ponds, excavated ponds, and stormwater basins, we used presence-absence data and multi-response permutation procedures (MRPP) to separately assess overall differences in vegetation, anuran, tadpole, and fish assemblages among wetland types. We also used MRPP to compare the relative abundance of calling anurans among wetland types. MRPP is designed to test for group differences in community data and was also used for post-hoc tests to compare wetland types (McCune and Grace 2002). The MRPP analyses were based on Sorensen distance and were completed using PC-ORD for Windows 6.08 (MjM Software, Gleneden Beach, OR, 1999).

To better interpret differences identified by the MRPP analyses, we applied the same ANOVA procedures used for the abiotic variables to compare plant, anuran, tadpole, and fish species richness and the various plant, anuran, tadpole, and fish biogeographic groups between wetland types. For three biotic variables that displayed no variance for at least one of the three wetland types (e.g. 0% Pine Barrens anuran species in stormwater basins), we used ANOVA with a White correction (White 1980). Because herbaceous species were included in the plant biogeographic groups, which we tested statistically, we evaluated differences in the most abundant herbaceous plant species at each site graphically.

Decontamination Procedures

We disinfected all wading and sampling gear between visits to each wetland. First, we used lawn and garden sprayers filled with tap water to rinse organic material from wading and sampling gear. To decontaminate wading gear, we stood in large plastic tubs and rinsed waders or boots using a sprayer that contained a 10% bleach solution, which is more concentrated than what is recommended by Bryan and others (2009) and Phillott and others (2010). For the fish and tadpole sampling, we used a clean dip net, seine, or cast net to sample each site and decontaminated all sampling gear at the end of each field day.

Results and Interpretations

Wetland Inventory

Wetland Mapping. We identified and delineated the perimeter for 5,850 wetlands in the Pinelands Area. These wetlands included 2,742 natural ponds, 1,690 excavated ponds, and 1,418 stormwater basins (Figure 4).

Wetland Inventory and Pinelands Management Areas. About 77% of all natural ponds were located in the two most ecologically protective Commission management areas: the Forest Area and Preservation Area District (Figure 5). Because of their location, most natural ponds were surrounded by relatively low amounts of developed land and upland agriculture (Figure 6). In the other seven management areas, excavated ponds outnumbered natural ponds and were therefore surrounded by greater amounts of developed and agricultural land than natural ponds. In contrast to these two types of ponds, almost 60% of all stormwater basins were located in the Regional Growth Area and displayed a relatively low amount of surrounding agricultural land and high amount of surrounding developed land.

Wetland Inventory and NJDEP Land-use Data. About 22% of the wetlands we mapped for our inventory using the 2007 aerial imagery were not mapped as any type of wetland in the 2007 NJDEP land-use data. These unmapped wetlands included 361 natural ponds, 386 excavated ponds, and 556 stormwater basins (Figure 7). We found similar results when comparing our inventory to the 2012 NJDEP land-use data.

The minimum mapping unit is defined as the size of the smallest feature on a map that is reliably mapped. According to the metadata for the 2007 and 2012 NJDEP land-use data, the minimum mapping unit is 1.0 ac (0.40 ha). For 2007, 360 of the 361 unmapped natural ponds, 375 of the 386 unmapped excavated ponds, and 520 of the 556 unmapped stormwater basins were smaller than the 1.0 ac minimum mapping unit used by the NJDEP, which is likely the reason these wetlands were not mapped as wetlands in the NJDEP land-use data. However, the few remaining unmapped wetlands (1 natural pond, 11 excavated ponds, and 36 stormwater basins) were larger than 1.0 ac and were mapped as various types of non-wetland habitat in the NJDEP land-use data.

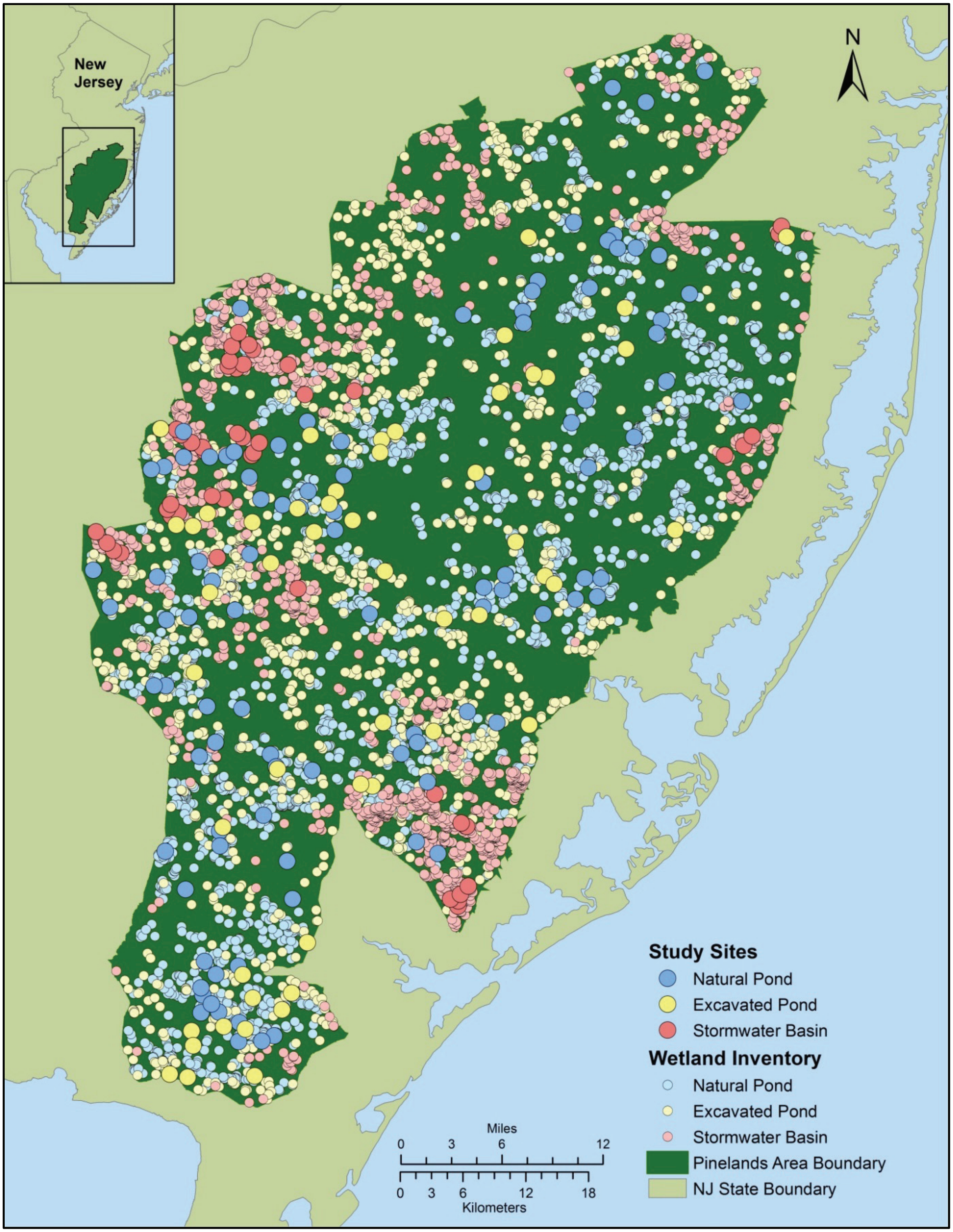

Figure 4. Inventory of 2,742 natural ponds, 1,690 excavated ponds, and 1,418 stormwater basins mapped in the Pinelands Area (smaller dots) and the 99 natural ponds, 52 excavated ponds, and 46 stormwater basins selected as study sites (larger dots).

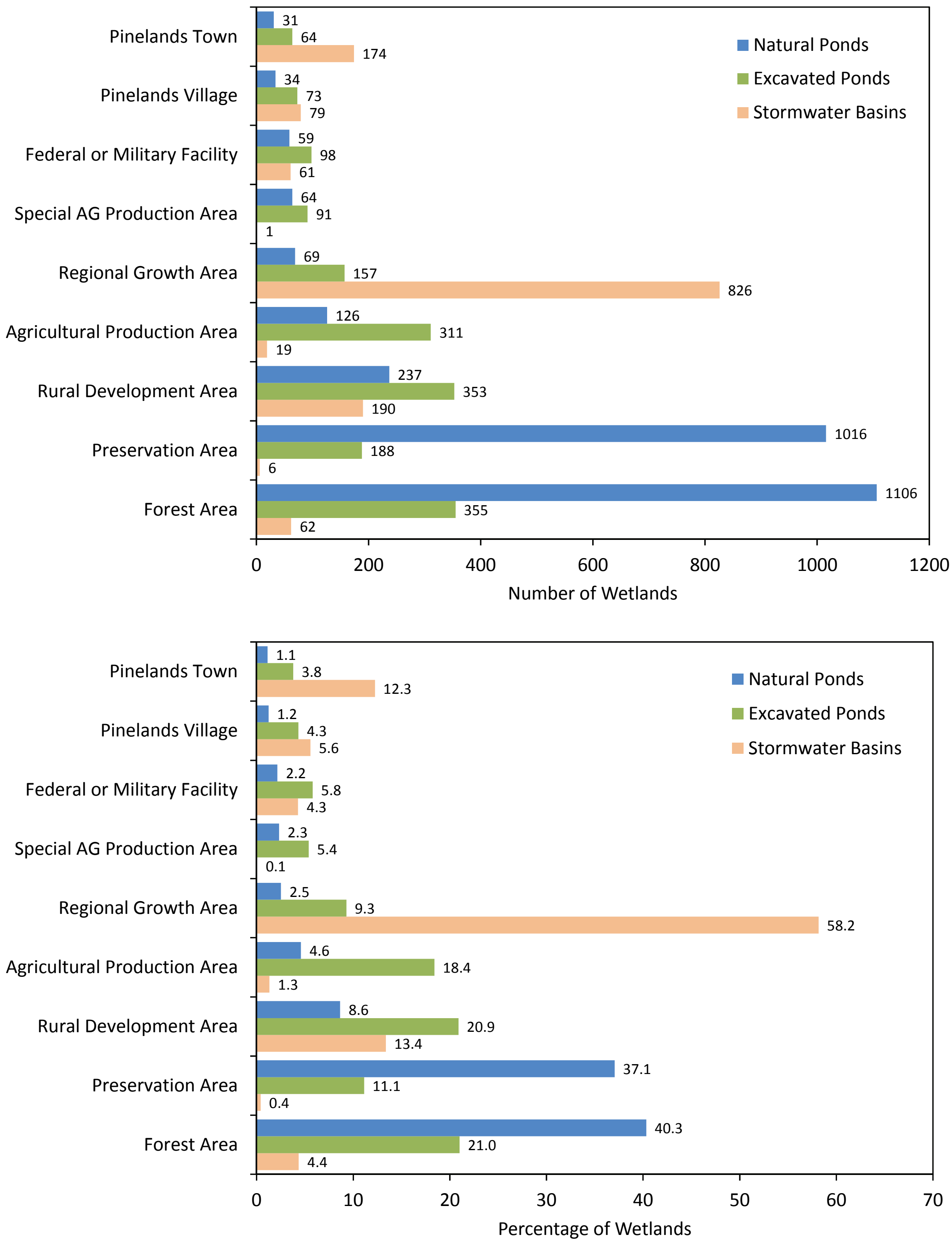

Figure 5. Number (top) and percentage (bottom) of 2,742 natural ponds, 1,690 excavated ponds, and 1,418 stormwater basins in each of the nine Pinelands Management Areas.

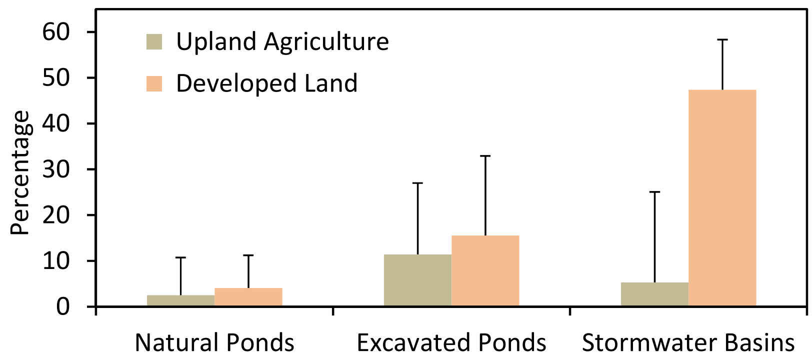

Figure 6. Mean (±1 SD) percentage of surrounding developed land and upland agriculture for 2,742 natural ponds, 1,690 excavated ponds, and 1,418 stormwater basins.

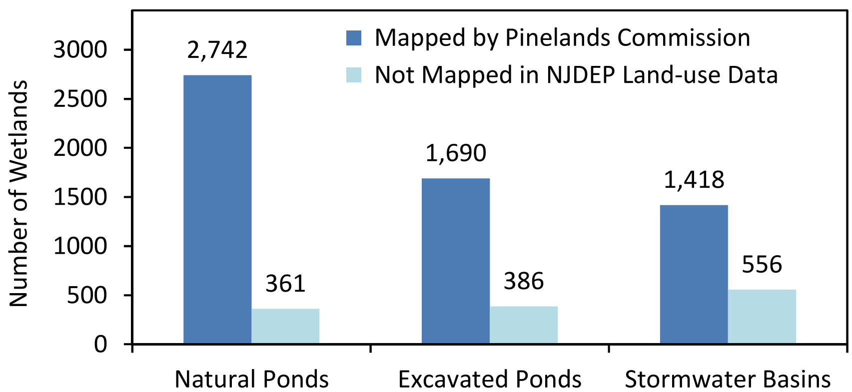

Figure 7. Number of natural ponds, excavated ponds, and stormwater basins in 2007 that were mapped by the Pinelands Commission and the number of each wetland type not included in the New Jersey Department of Environmental Protection 2007 land-use/land-cover update (NJDEP 2010).

Wetland Vulnerability at Buildout

Buildout and Pinelands Management Areas. Surrounding developed land increased at buildout for almost all of the natural and excavated ponds located in the following Pinelands Management Areas: Rural Development Area, Pinelands Town, Pinelands Village, and Regional Growth Area (Figure 8). This finding is not surprising given that we converted buildable land in these four management areas to development for the buildout scenario, but does highlight the potential vulnerability of these wetlands in development-oriented areas. For most management areas, average increases in surrounding developed land were greater for excavated ponds compared to natural ponds (Figure 9). The percentage of natural and excavated ponds that showed an increase in surrounding developed land and the average increase in surrounding developed land was greatest for the Rural Development Area (Figures 8 and 9). Figure 10 shows the shift in surrounding developed land before and after buildout for natural and excavated ponds located in each of the four development areas.

Because we did not simulate a change in developed land in the Agricultural Production Area, Forest Area, Federal or Military Facility, Preservation Area, and Special Agricultural Production Area, the increase in surrounding developed land at buildout for ponds located in these non-development-oriented management areas was due to the close proximity of the ponds to the four development areas (Figures 8 and 9). We observed only small differences in the buildout results when we completed the buildout analysis using a 250-m versus the 500-m radius polygon, which indicated that polygon size did not play a significant role in the overall results of the analysis.

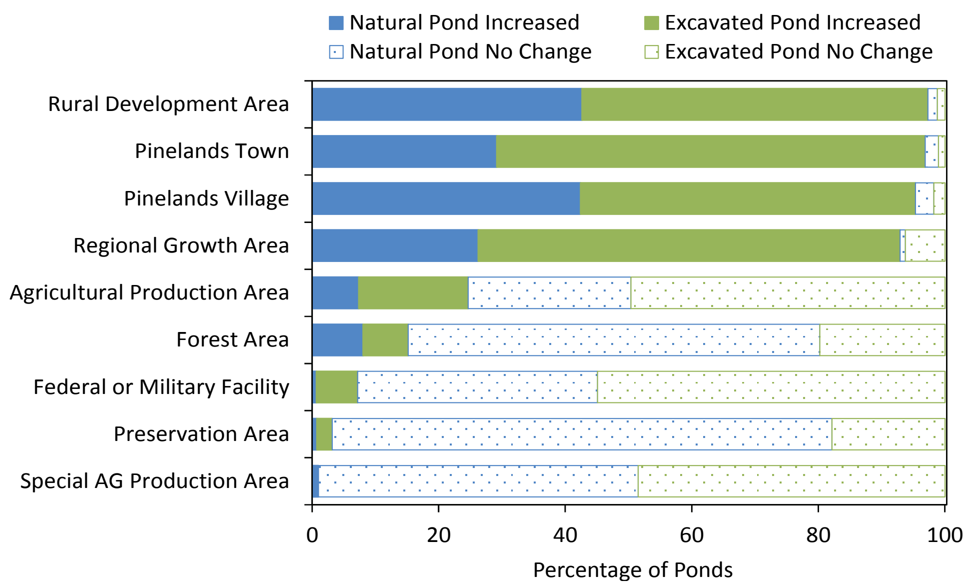

Figure 8. Percentage of natural and excavated ponds in each of the nine Pinelands management areas that showed either an increase or no change in surrounding developed land at buildout.

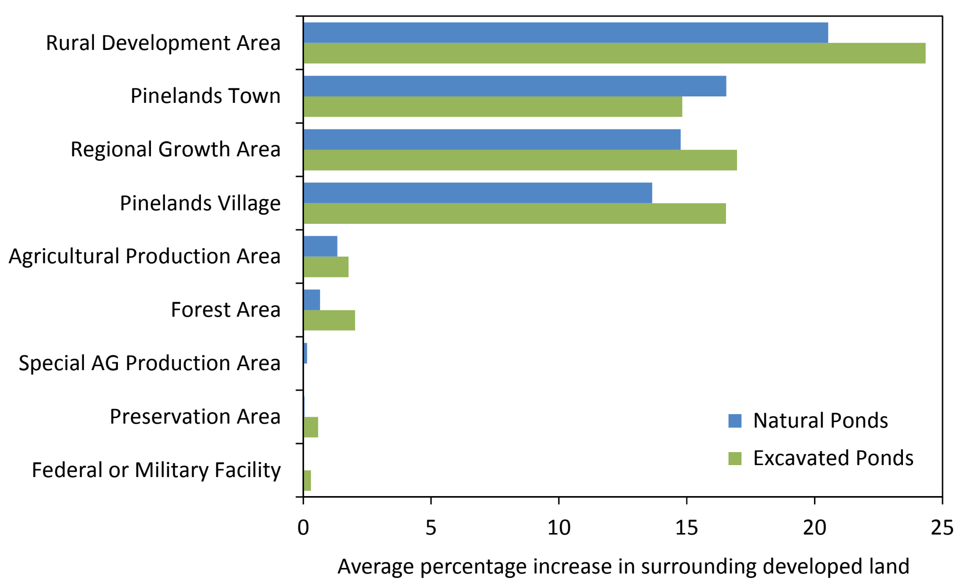

Figure 9. Mean percentage increase in surrounding developed land between 2012 and buildout for natural and excavated ponds in each of the nine Pinelands management areas.

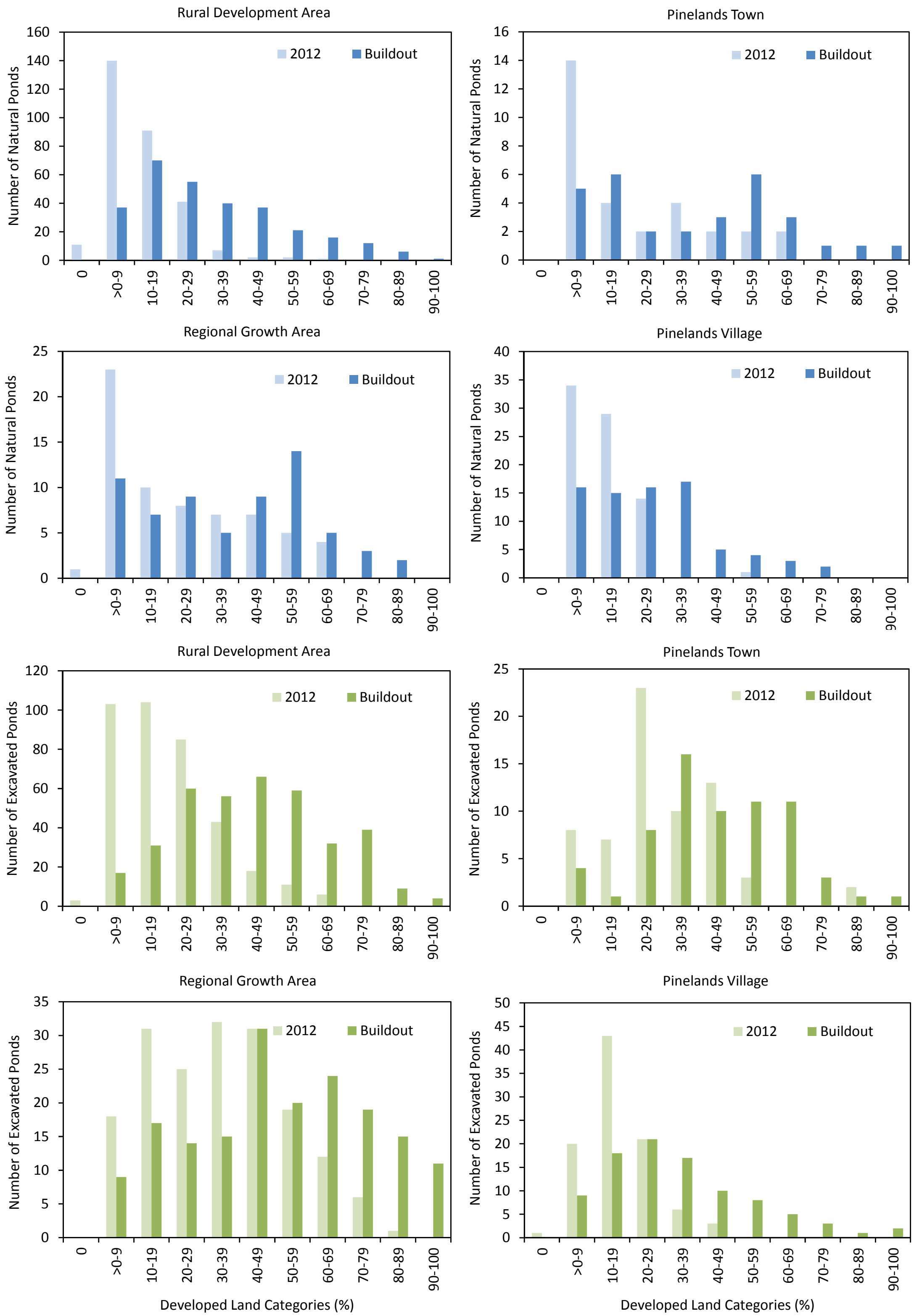

Figure 10. Number of natural and excavated ponds in various 10% developed land categories in 2012 and at buildout for the four Pinelands Management Areas where development is directed.

Modeling Non-native Plants and Pond pH at Buildout. We used data from the 151 natural and excavated study ponds to develop a model to estimate increases in the percentage of non-native herbaceous plant species between 2012 and buildout for the remaining 2,643 natural ponds and 1,638 excavated ponds. In 2012, the average estimated percentage of non-native herbaceous plant species for natural ponds ranged from 6.5% for the Special Agricultural Production Area to 27.5% for the Regional Growth Area and for excavated ponds ranged from 5.6% in the Special Agricultural Production Area to 44.2% in the Agricultural Production Area (Figure 11).

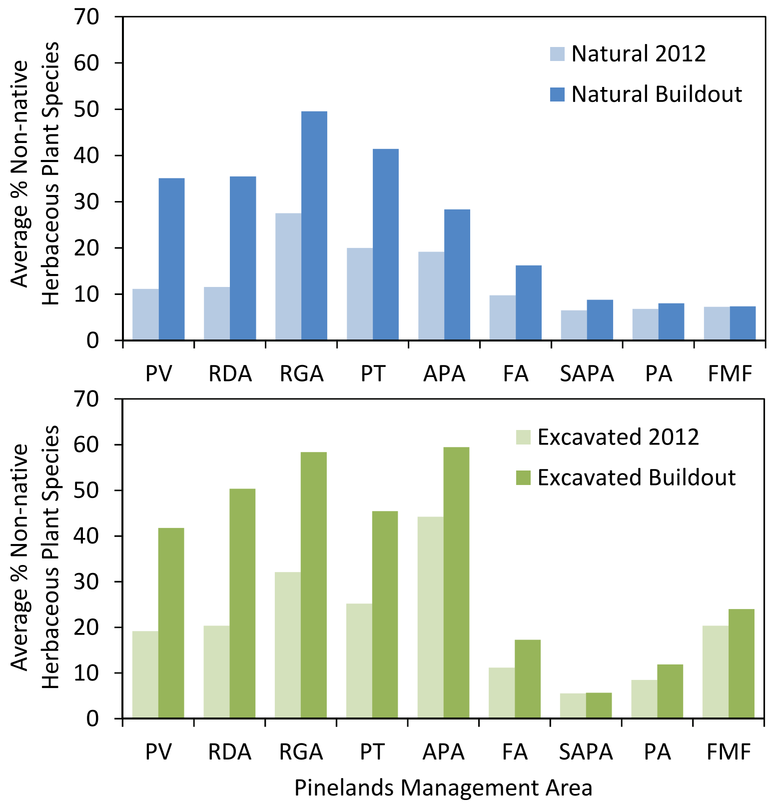

Figure 11. Estimated average percentage of non-native herbaceous plant species for natural and excavated ponds in 2012 and at buildout in each Pinelands Management Area. Management areas, which are ordered by decreasing difference in the percentage between the two periods, are PV = Pinelands Village, RDA = Rural Development Area, RGA = Regional Growth Area, PT = Pinelands Town, APA = Agricultural Production Area, FA = Forest Area, SAPA = Special Agricultural Production Area, PA = Preservation Area, and FMF = Federal or Military Facility.

About 19% (499) of natural ponds and 52% (848) of excavated ponds showed a predicted increase in non-native herbaceous plant species between 2012 and buildout. As expected, the greatest increases occurred in the four development-oriented areas (Figure 11). From 2012 to buildout, the estimated average percentage of non-native herbaceous plant species per pond nearly doubled in the Regional Growth Area, doubled in the Pinelands Town management area, and more than tripled for both the Pinelands Village management areas and the Rural Development Area. For the same period, increases in the estimated percentage of non-native herbaceous plant species per pond were similar for excavated ponds in the four development-oriented areas. Much smaller increases in the estimated percentage of non-native herbaceous plant species occurred in most of the other management areas.

Like the analysis for non-native plants, we used data from the 151 natural and excavated study ponds to develop a model to estimate changes in pond pH between 2012 and buildout for the remaining 2,643 natural ponds and 1,638 excavated ponds. Although a small percentage of natural and excavated ponds was estimated to increase more than 0.5 pH units at buildout, about 96% of the natural ponds and 88% of the excavated ponds indicated little or no change in pH at buildout (Figure 12). Twelve natural ponds and 28 excavated ponds were estimated to increase more than a whole pH unit, which equates to a pond becoming ten times less acidic. No pond was estimated to increase by more than 1.5 pH units.

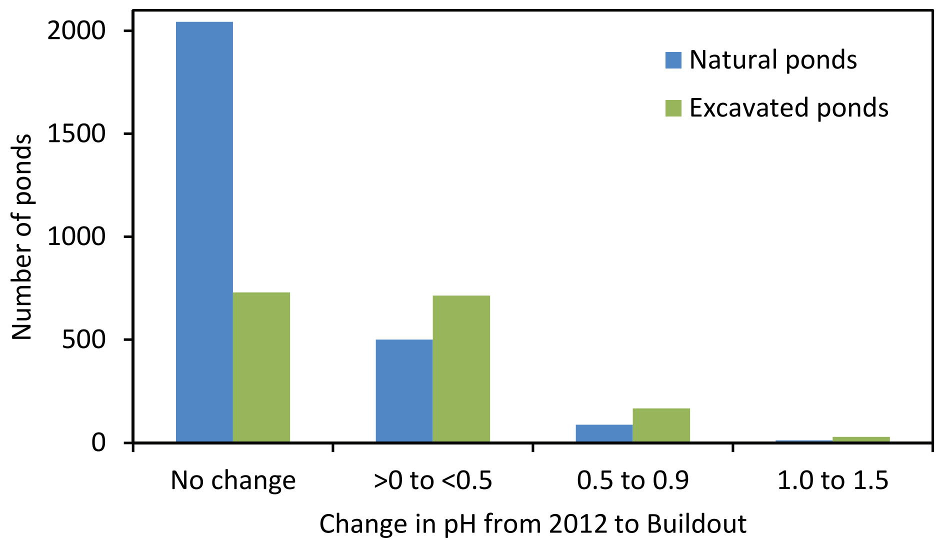

Figure 12. Number of natural and excavated ponds that changed by different pH categories from 2012 to buildout.

Wetland Vulnerability to Off-road Vehicle Damage

Off-road Vehicle Damage Surveys. Of the 4,432 natural and excavated ponds in our wetland inventory, we surveyed 3,585 for off-road vehicle damage using 2007 aerial imagery and completed on-ground surveys at the remaining 847 ponds in 2013 - 2017 (2013: 69 ponds, 2014: 66 ponds, 2015: 35 ponds, 2016: 35 ponds, and 2017: 642 ponds). For aerial and on-ground surveys together, we observed off-road vehicle damage at 195 wetlands, including 84 natural ponds and 111 excavated ponds (Table 2).

For the on-ground surveys, we found that 117 of the 847 ponds were damaged by vehicles, and 46 of these ponds displayed extensive vehicle damage. Vehicles used to drive in ponds included motorcycles, all-terrain vehicles (i.e., quads), and trucks. The number of vehicle access points at damaged ponds ranged from one to six. Eighteen of the 847 ponds were accessible by some sort of trail or road, but did not appear to be damaged by vehicles. We found yard waste at seven ponds, debris piles at 14 ponds, and trash dumped at 60 ponds. Ditches or firebreaks existed at 20 ponds, stormwater pipes were present at 10 ponds, and eight ponds appeared to be party spots. A total of 51 ponds were determined to require immediate protection to prevent future vehicle damage. Of these 51 ponds, 32 ponds already displayed extensive vehicle damage, 12 exhibited minimal damage, and seven contained no damage.

State-owned vs. Non-state-owned Land. About 40% of all natural and excavated ponds that we identified were located on state-owned land and 60% were located on non-state-owned land. More natural ponds were located on state-owned and more excavated ponds were situated on non-state-owned land (Table 2). For state land, the greatest number of ponds occurred on Division of Parks and Forests land (916 natural and 154 excavated), an intermediate number of ponds occurred on Division of Fish and Wildlife land (577 natural and 75 excavated), and the lowest number of ponds occurred on Natural Lands Trust property (49 natural and 17 excavated). Pond density was similar for the three land-management units at 0.012, 0.013, and 0.013 ponds/ha for Division of Fish and Wildlife, Parks and Forests, and Natural Lands Trust properties, respectively. The percentage of natural ponds that were damaged in each of the three state land units was similar at about 4%, whereas the percentage of excavated ponds that were damaged on state land was greater overall and ranged from 16% on Fish and Wildlife land to 47% on Natural Land Trust land. For non-state-owned land, the percentage of natural ponds with damage was 2% and the percentage of excavated ponds with damage was 4%.

Off-road Vehicle Damage Model. Logistic regression showed that off-road vehicle damage at ponds was related to five of the ten variables analyzed. The significant variables were pond area, percentage of open water, percentage of herbaceous vegetation, distance to the nearest damaged pond, and distance to the nearest road. The percentage of tree cover and shrub cover, percentage of surrounding developed land and upland agriculture, and distance to nearest approved enduro route were not related to vehicle damage at ponds. Ponds that were larger, with greater amounts of open water and herbaceous vegetation cover, near other damaged ponds, and close to sand or paved roads tended to be damaged by off-road vehicles more than smaller ponds with greater shrub and tree cover that were either located in developed or farmed landscapes or in less accessible and remote areas of the forest (Figure 13). We used the logistic regression model with the five significant variables to determine the probability of a pond being damaged by off-road vehicles and then categorized the probabilities into three risk levels: low (<25% chance of being damaged), medium (25-50% chance of being damaged), and high (>75% chance of being damaged, Figure 14).

Table 2. Number of natural and excavated ponds with and without off-road vehicle damage and the percentage of each that are damaged. Ponds are grouped based on whether they were located on land managed by the New Jersey Department of Environmental Protection Division of Fish and Wildlife, Division of Parks and Forests, and Natural Lands Trust or located on non-state owned land. Off-road vehicle damage was assessed at 3,585 ponds using aerial imagery from 2007 and at 847 ponds during on-ground visits in 2013-2017.

Land Owner	Natural Ponds				Excavated Ponds				All Ponds	
Land Management Unit Name	With Damage	No Damage	Total Number	% Damaged	With Damage	No Damage	Total Number	% Damaged	Total Number	% Damaged
Fish and Wildlife: Wildlife Management Areas										
Cedar Lake	1	1	2	50%	-	-	-	-	2	50%
Colliers Mills	0	22	22	0%	0	3	3	0%	25	0%
Forked River Mountain	2	26	28	7%	1	0	1	100%	29	10%
Great Egg Harbor River	0	29	29	0%	1	10	11	9%	40	3%
Greenwood Forest	6	112	118	5%	1	5	6	17%	124	6%
Hammonton Creek	1	18	19	5%	1	6	7	14%	26	8%
Makepeace Lake	2	39	41	5%	0	7	7	0%	48	4%
Manchester	0	1	1	0%	-	-	-	-	1	0%
Maple Lake	0	5	5	0%	0	4	4	0%	9	0%
Peaslee	3	187	190	2%	0	13	13	0%	203	1%
Port Republic	-	-	-	-	0	2	2	0%	2	0%
Stafford Forge	4	57	61	7%	6	6	12	50%	73	14%
Swan Bay	0	10	10	0%	0	1	1	0%	11	0%
White Oak Branch	1	12	13	8%	0	1	1	0%	14	7%
Winslow	3	33	36	8%	2	5	7	29%	43	12%
White Oaks Golf Course	0	2	2	0%	-	-	-	-	2	0%
Fish and Wildlife Total	23	554	577	4%	12	63	75	16%	652	5%
Parks and Forests: State Park and State Forest Land										
Bass River SF	2	134	136	1%	1	20	21	5%	157	2%
Belleplain SF	6	195	201	3%	5	34	39	13%	240	5%
Brendan T. Byrne SF	7	143	150	5%	10	13	23	43%	173	10%
Penn SF	1	31	32	3%	-	-	-	-	32	3%
Wharton SF	19	364	383	5%	19	48	67	28%	450	8%
Double Trouble State Park	1	11	12	8%	2	0	2	100%	14	21%
Forest Resource Educ. Cntr.	0	2	2	0%	1	1	2	50%	4	25%
Parks and Forests Total	36	880	916	4%	38	116	154	25%	1070	7%
Natural Lands Trust Land Preserves										
Babcock Creek Preserve	0	1	1	0%	-	-	-	-	1	0%
Barnegat Preserve	0	2	2	0%	-	-	-	-	2	0%
Bears Head Preserve	0	5	5	0%	-	-	-	-	5	0%
Black Acres Preserve	0	1	1	0%	-	-	-	-	1	0%
Hamilton Preserve	1	8	9	11%	6	4	10	60%	19	37%
Hirst Ponds Preserve	0	4	4	0%	0	1	1	0%	5	0%
Long-A-Coming Preserve	1	2	3	33%	-	-	-	-	3	33%
Mankiller Preserve	0	10	10	0%	0	2	2	0%	12	0%
Monroe Preserve	0	1	1	0%	-	-	-	-	1	0%
Pancoast Preserve	0	1	1	0%	-	-	-	-	1	0%
Penny Pot Preserve	0	3	3	0%	2	0	2	100%	5	40%
Retreat Preserve	-	-	-	-	0	1	1	0%	1	0%
Sooy Place Preserve	0	9	9	0%	0	1	1	0%	10	0%
Natural Lands Trust Total	2	47	49	4%	8	9	17	47%	66	15%
All State Land	61	1481	1542	4%	58	188	246	24%	1788	7%
Non-state Land	23	1177	1200	2%	53	1391	1444	4%	2644	3%
Grand Total	84	2658	2742	3%	111	1579	1690	7%	4432	4%

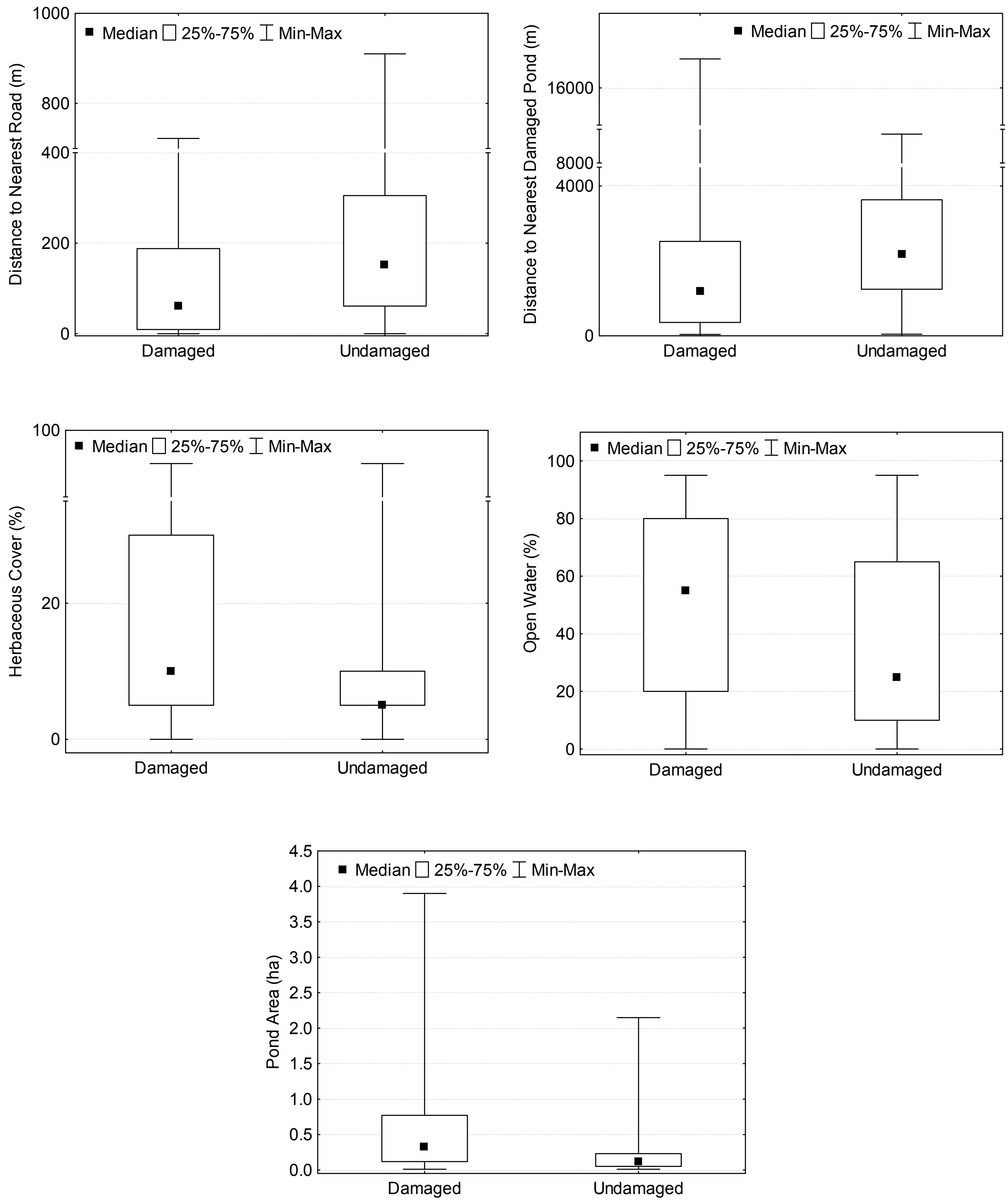

Figure 13. Box plots showing significant differences in five variables between damaged and undamaged natural and excavated ponds.

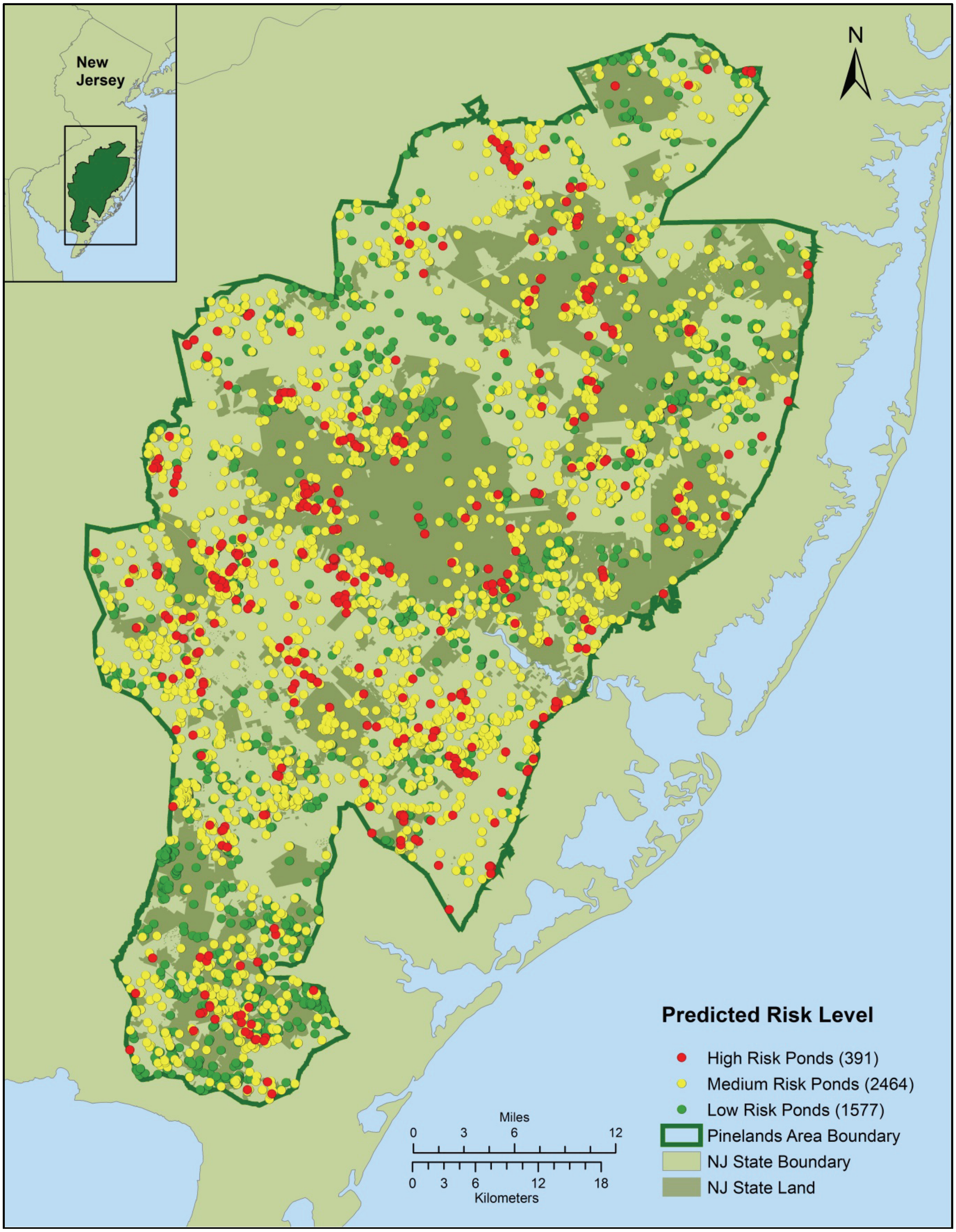

Figure 14. Predicted vulnerabilty to off-road vehicle damage for 4,432 natural and excavated ponds in the Pinelands. High risk = >75% , medium risk = 50-75%, and low risk = <25% chance of being damaged by off-road vehicles. Risk levels were derived from a statistical model that used pond size, the amount of open water and herbaceous vegetation, and the distance to the nearest road and the nearest damaged pond.

Dragonfly and Damselfly Assemblages as Indicators of Land Use

Dragonfly and Damselfly Inventory. A total of 59 species (38 dragonfly and 21 damselfly species) were found at the 33 natural ponds that were surveyed for odonates (Table 3). The 59 species included 37 adult and 16 larval dragonfly species and 21 adult and 9 larval damselfly species. Total species richness per pond ranged from 6 to 32, with a median of 14 species per site. Fragile forktail (*Ischnura posita*) and blue dasher (*Pachydiplax longipennis*) occurred at almost all of the ponds. About one-third of the species occurred at a maximum abundance of greater than 20 individuals. Three species recorded in our surveys are classified as Special Concern by the NJDEP Endangered and Nongame Species Program (*Libellula auripennis* or golden-winged skimmer, *Enallagma pictum* or scarlet bluet, and *Enallagma recurvatum* or Pine Barrens bluet, Table 3).

Dragonfly and Damselfly Assemblages. The first axis of the combined odonate ordination contrasted species associated with swamps and wooded wetlands at the extreme left side of the ordination diagram with species associated with open bogs and lakes at the extreme right side of the diagram (Figure 15). We found a significant positive correlation between the first-axis site scores of the combined odonate ordination and pond area and species richness and a significant negative correlation between the site scores and tree cover and developed land (Table 4). Ponds placed on the left side of the ordination diagram were generally smaller, supported fewer species, displayed greater tree-canopy cover, and contained more surrounding developed land compared to ponds placed on the right side of the ordination diagram (Figure 16). We found no significant correlations between the combined ordination scores and pH, specific conductance, upland agriculture, or drying frequency (Table 4). We found a significant correlation between the first-axis site scores of the combined ordination and the other three ordinations, which showed that all four ordinations produced similar results (Table 4).

Using the Rhode Island degradation classification, conservation scores assigned to the odonate species ranged from 0 to 10, with a median of 5.7. Ten species could not be classified. Averaging species conservation scores for a site resulted in site conservation scores that ranged from 5.1 to 6.4, with a median of 5.8. We found no significant correlation between species and site conservation scores and the first-axis species ($r = -0.09$, $p = 0.531$) and site scores ($r = 0.09$, $p = 0.609$) produced from the combined ordination. Although the ordination scores were related to surrounding developed land, the lack of a relationship between the ordination scores and surrounding agricultural land, pH, specific conductance, and the Rhode Island degradation classification suggests that odonate assemblages in natural ponds may be more influenced by forest canopy cover and wetland size rather than surrounding land use. Additional research is needed to determine if land use plays a role in shaping the composition of odonate assemblages in natural ponds, as well as in other Pinelands waters, such as streams and impoundments.

Table 3. Frequency of occurrence and minimum and maximum abundance for dragonfly and damselfly adults and exuviae at 33 natural Pinelands ponds. An asterisk denotes species listed as Special Concern by the New Jersey Department of Environmental Protection https://www.nj.gov/dep/fgw/ensp/pdf/spclspp.pdf.

			Adults			Exuviae		
Scientific name	Common name	DCA code	Freq.	Min.	Max.	Freq.	Min.	Max.
Damselflies								
Argia bipunctulata	seepage dancer	DancSeep	5	1	6	-	-	-
Calopteryx maculata	ebony jewelwing	JeweEbon	5	1	2	-	-	-
Enallagma aspersum	azure bluet	BlueAzur	20	1	>20	-	-	-
Enallagma doubledayi	Atlantic bluet	BlueAtla	3	1	>10	-	-	-
Enallagma geminatum	skimming bluet	BlueSkim	1	2	2	2	1	31
**Enallagma pictum*	scarlet bluet	BlueScar	3	1	2	-	-	-
**Enallagma recurvatum*	Pine Barrens bluet	BluePine	2	1	1	1	11	11
Enallagma signatum	orange bluet	BlueOran	2	1	1	-	-	-
Ischnura hastata	citrine forktail	ForkCitr	14	1	>20	-	-	-
Ischnura kellicotti	lilypad forktail	ForkLily	1	1	1	-	-	-
Ischnura posita	fragile forktail	ForkFrag	31	1	>20	3	1	10
Ischnura ramburii	Rambur's forktail	ForkRamb	2	1	1	1	5	5
Ischnura verticalis	eastern forktail	ForkEast	10	1	>20	-	-	-
Lestes congener	spotted spreadwing	SpreSpot	3	1	3	1	3	3
Lestes eurinus	amber-winged spreadwing	SpreAmbe	4	1	>10	-	-	-
Lestes forcipatus	sweetflag spreadwing	SpreSwee	3	1	>20	8	1	12
Lestes rectangularis	slender spreadwing	SpreSlen	9	1	>20	3	11	14
Lestes vigilax	swamp spreadwing	SpreSwam	2	1	1	4	1	5
Nehalennia gracilis	sphagnum sprite	SpriSpha	12	1	>20	3	1	12
Nehalennia integricollis	southern sprite	SpriSout	3	1	>20	-	-	-
Nehalennia irene	sedge sprite	SpriSedg	1	1	1	-	-	-
Dragonflies								
Anax junius	common green darner	DarnComm	24	1	4	11	1	6
Anax longipes	comet darner	DarnCome	8	1	5	1	2	2
Celithemis elisa	calico pennant	PennCali	6	1	>10	2	7	10
Celithemis eponina	halloween pennant	PennHall	1	1	1	-	-	-
Celithemis martha	Martha's pennant	PennMart	5	1	>20	-	-	-
Celithemis verna	double-ringed pennant	PennDoub	8	1	>10	2	1	3
Dorocordulia lepida	petite emerald	EmerPeti	1	1	1	-	-	-
Epiaeschna heros	swamp darner	DarnSwam	13	1	3	-	-	-
Epitheca cynosura	common baskettail	BaskComm	1	1	1	-	-	-
Epitheca semiaquea	mantled baskettail	BaskMant	2	1	2	-	-	-
Erythemis simplicicollis	eastern pondhawk	PondEast	24	1	>20	5	1	9
Gomphaeschna furcillata	harlequin darner	DarnHarl	3	1	1	-	-	-
Hagenius brevistylus	dragonhunter	DragHunt	5	1	4	-	-	-
Ladona deplanata	blue corporal	CorpBlue	5	1	>20	-	-	-
Ladona exusta	white corporal	CorpWhit	3	1	8	-	-	-
Leucorrhinia intacta	dot-tailed whiteface	WhitDott	-	-	-	1	4	4
**Libellula auripennis*	golden-winged skimmer	SkimGold	2	1	1	-	-	-
Libellula axilena	bar-winged skimmer	SkimBarw	24	1	>20	-	-	-
Libellula cyanea	spangled skimmer	SkimSpan	6	1	6	-	-	-
Libellula flavida	yellow-sided skimmer	SkimYell	5	1	6	-	-	-
Libellula incesta	slaty skimmer	SkimSlat	19	1	>20	-	-	-
Libellula luctuosa	widow skimmer	SkimWido	1	2	2	-	-	-
Libellula pulchella	twelve-spotted skimmer	SkimTwel	6	1	2	1	1	1
Libellula semifasciata	painted skimmer	SkimPain	26	1	>20	7	1	19
Libellula vibrans	great blue skimmer	SkimGrea	15	1	8	1	1	1
Nannothemis bella	elfin skimmer	SkimElfi	5	1	>20	-	-	-
Nasiaeschna pentacantha	cyrano darner	DarnCyra	2	1	1	-	-	-
Pachydiplax longipennis	blue dasher	DashBlue	30	1	>20	18	1	71
Pantala flavescens	wandering glider	GlidWand	1	2	2	-	-	-
Perithemis tenera	eastern amberwing	AmbeEast	4	2	>20	-	-	-
Plathemis lydia	common whitetail	WhitComm	12	1	>10	2	1	1
Somatochlora filosa	fine-lined emerald	EmerFine	2	1	1	-	-	-
Sympetrum ambiguum	blue-faced meadowhawk	MeadBlue	17	1	>20	3	2	51
Sympetrum internum	cherry-faced meadowhawk	MeadCher	11	1	>20	1	1	1
Sympetrum obtrusum	white-faced meadowhawk	MeadWhit	1	1	2	1	2	2
Sympetrum vicinum	autumn meadowhawk	MeadAutu	17	1	>20	5	1	29
Tramea carolina	Carolina saddlebags	SaddCaro	20	1	>20	10	1	35
Tramea lacerata	black saddlebags	SaddBlac	2	1	2	-	-	-

Table 4. Spearman rank correlation results between the combined adult and larval dragonfly and damselfly DCA axis 1 site scores and the adults-only, dragonfly-only, and damselfly-only DCA axis 1 site scores and between the combined DCA site scores and environmental variables.

Comparisons	r	p-value
Axis 1 combined vs. Axis 1 adults only	0.99	<0.000
Axis 1 combined vs. Axis 1 dragonfly only	0.98	<0.000
Axis 1 combined vs. Axis 1 damselfly only	0.83	<0.000
Axis 1 combined vs. pond area	0.79	<0.000
Axis 1 combined vs. species richness	0.79	<0.000
Axis 1 combined vs. tree canopy cover	-0.77	<0.000
Axis 1 combined vs. developed land	-0.60	<0.001
Axis 1 combined vs. upland agriculture	-0.34	0.055
Axis 1 combined vs. pH	-0.26	0.150
Axis 1 combined vs. drying frequency	-0.24	0.170
Axis 1 combined vs. specific conductance	0.08	0.656

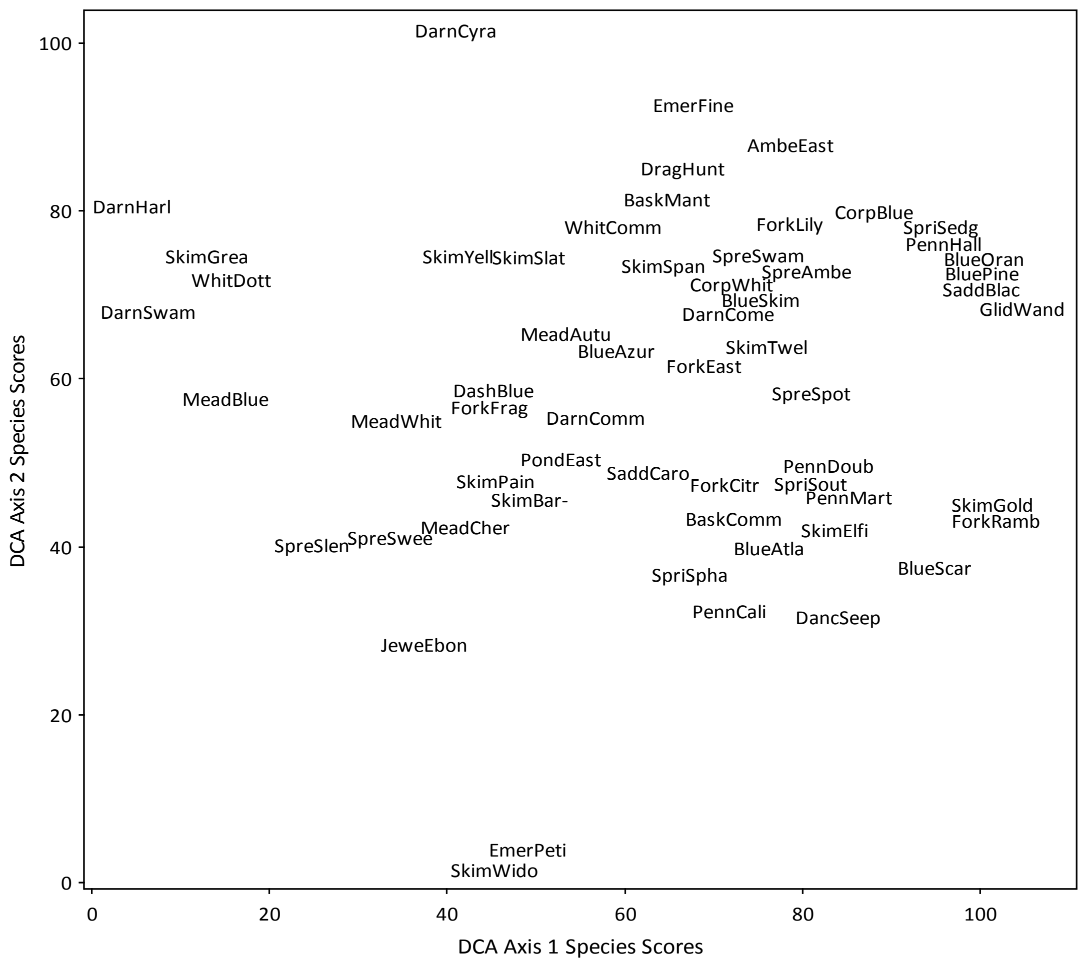

Figure 15. Detrended correspondence analysis (DCA) species diagram for dragonfly and damselfly larva and adults from 33 natural ponds.

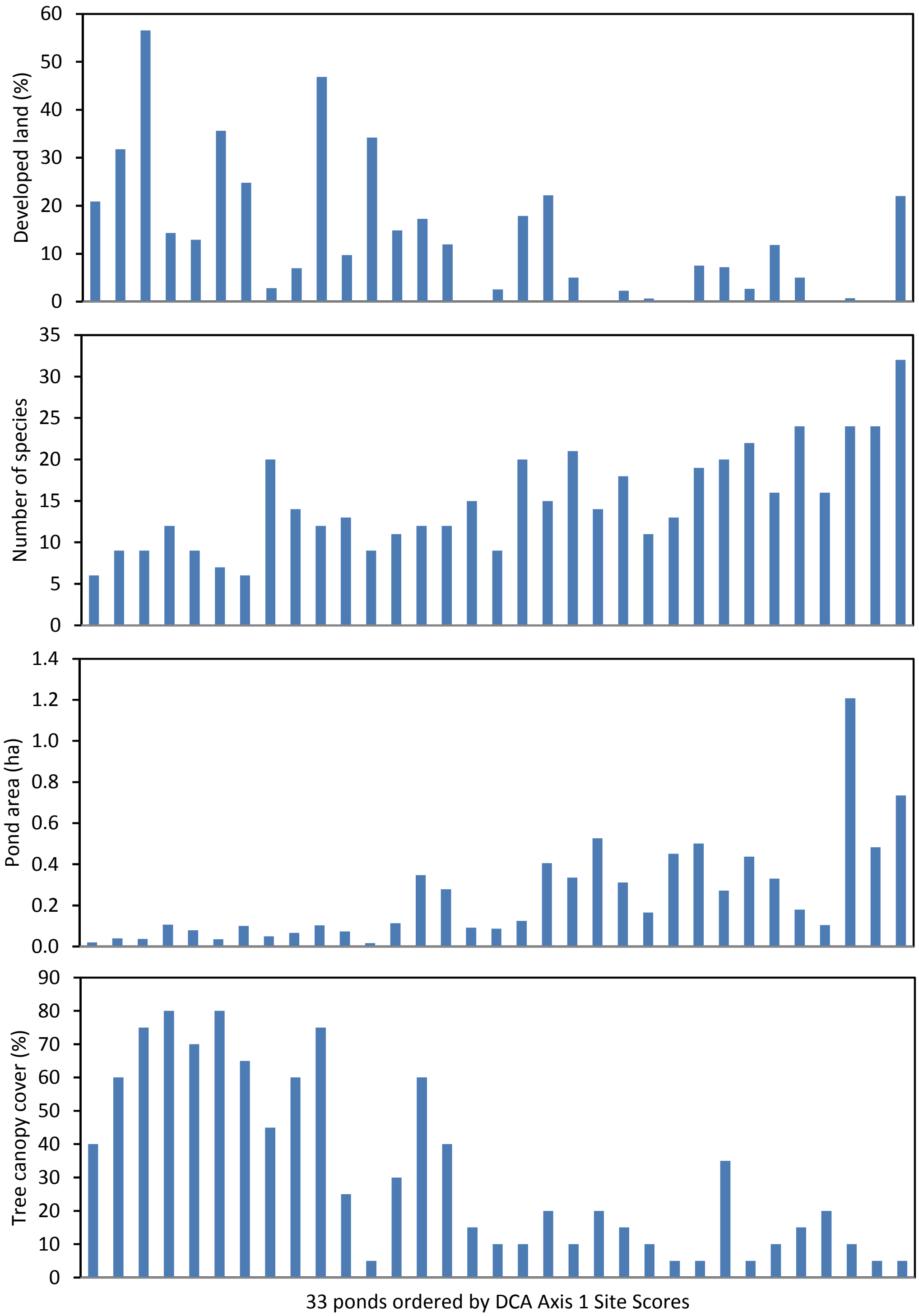

Figure 16. The percentage of surrounding developed land, number of dragonfly and damselfly species, pond area, and percentage tree canopy cover for 33 natural ponds. Ponds are ordered by the first axis site scores from the detrended correspondence analysis (DCA) of combined adult and larval dragonfly and damselfly species.

Comparability of Natural and Created Wetlands

Study Sites. For this analysis, we selected 197 study sites from the wetland inventory, including 99 natural ponds, 52 excavated ponds, and 46 stormwater basins. Although natural ponds in the Pinelands may have formed from periglacial wind action around 16-18,000 years ago (French and Demitroff 2001), the average (±1 SD) age of the 52 excavated ponds and 46 stormwater basins from the time they were first visible on aerial imagery to 2018 was 60 (±21) years and 19 (±4) years, respectively.

Land Use. We found a significant difference in the amount of surrounding developed land between wetland types. Stormwater basins displayed greater amounts of surrounding developed land compared to both natural and excavated ponds (Table 5, Figure 17). We found no differences in surrounding upland agricultural land for any of the three wetland types.

Forest Hydrology. We found a significant difference in the percentage of surrounding upland forest, wetland forest, and non-forest among wetland types. Natural ponds were located in the wettest landscapes, excavated ponds in the driest landscapes, and stormwater basins were surrounded by greater amounts of non-forest (Table 5, Figure 18).

Wetland Habitat Structure. We observed a significant difference in wetland area among wetland types with natural ponds being larger than both excavated ponds and stormwater basins (Table 5, Figure 19). We also found a significant difference in the percentage of all four habitat structure variables: tree cover, shrub cover, herbaceous cover, and water cover (Table 5, Figure 19). Tree cover was highest and herbaceous cover lowest for natural and excavated ponds compared to stormwater basins. Shrub cover was greatest for natural ponds, intermediate for excavated ponds, and lowest for stormwater basins. Only natural and excavated ponds differed in the amount of water cover with excavated ponds possessing a greater amount of open water.

Wetland Hydrology. Fourteen natural ponds, 21 excavated ponds, and 11 stormwater basins contained at least some water during the 18 visits for water level measurements. The remaining 151 wetlands were dry from one to 16 of the 18 visits. We found a significant difference in the mean water depth, mean water-depth fluctuation, and mean frequency of drying among wetland types (Table 5, Figure 20). Excavated ponds were deeper than natural ponds and stormwater basins, natural ponds and stormwater basins dried more often than excavated ponds, and natural and excavated ponds exhibited greater water-depth fluctuations than basins.

Water Quality. Although we visited the 197 wetlands twice per year to measure pH, specific conductance, and temperature for a total of six measurements, we obtained fewer than six measurements for 37 wetlands because of little or no water during the sampling events (Table 6).

We observed a significant difference in median pH, specific conductance, and temperature between wetland types (Table 5, Figure 21). Median pH differed between all three wetland types with natural ponds being the most acidic and stormwater basins displaying the highest pH values. Specific conductance did not differ between natural and excavated ponds, but values were greater for stormwater basins. Water temperature was lower for excavated ponds compared to both natural ponds and stormwater basins.

Table 5. Analysis of variance (ANOVA) and post-hoc test results for environmental attributes. Only significant p-values are given, ns = not significant.

		Post-hoc Test Results		
Environmental Attribute	ANOVA	Natural vs. Excavated	Excavated vs. Stormwater	Natural vs. Stormwater
Land use (within 500 m)				
% Developed land	<0.001	ns	<0.001	<0.001
% Upland agriculture	ns	ns	ns	ns
Water quality				
Median pH	<0.001	<0.001	<0.001	<0.001
Median specific conductance	0.005	ns	0.016	0.005
Median water temperature	0.002	0.035	0.002	ns
Wetland hydrology				
Mean water depth	0.001	<0.001	0.014	ns
Mean frequency of drying	0.010	0.048	0.012	ns
Mean water-depth fluctuation	<0.001	ns	<0.001	0.005
Wetland structure (within perimeter)				
Wetland area	<0.001	<0.001	ns	0.007
% Tree cover	<0.001	ns	<0.001	<0.001
% Shrub cover	<0.001	<0.001	0.023	<0.001
% Herbaceous cover	<0.001	ns	<0.001	<0.001
% Water cover	0.003	0.002	ns	ns
Forest hydrology (within 25 m)				
% Upland Forest	<0.001	<0.001	<0.001	ns
% Wetland Forest	<0.001	<0.001	<0.001	<0.001
% Non-forest	<0.001	ns	<0.001	<0.001
Number of differences		9	13	10

Table 6. Number of water-quality samples out of a maximum of six obtained for the 197 natural ponds, excavated ponds, and stormwater basins.

Number of WQ samples	Natural ponds	Excavated ponds	Stormwater basins	Total # sites
2	1	-	1	2
3	-	-	2	2
4	2	1	8	11
5	6	-	16	22
6	90	51	19	160
Total # of sites	99	52	46	197

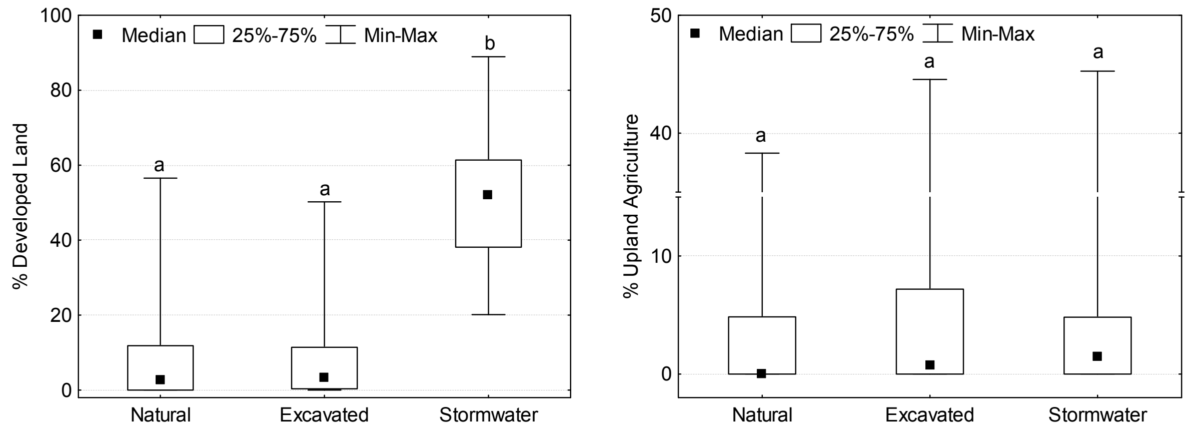

Figure 17. Box plots showing the percentage of surrounding developed land and upland agriculture for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins. Different letters indicate significant differences between wetland types.

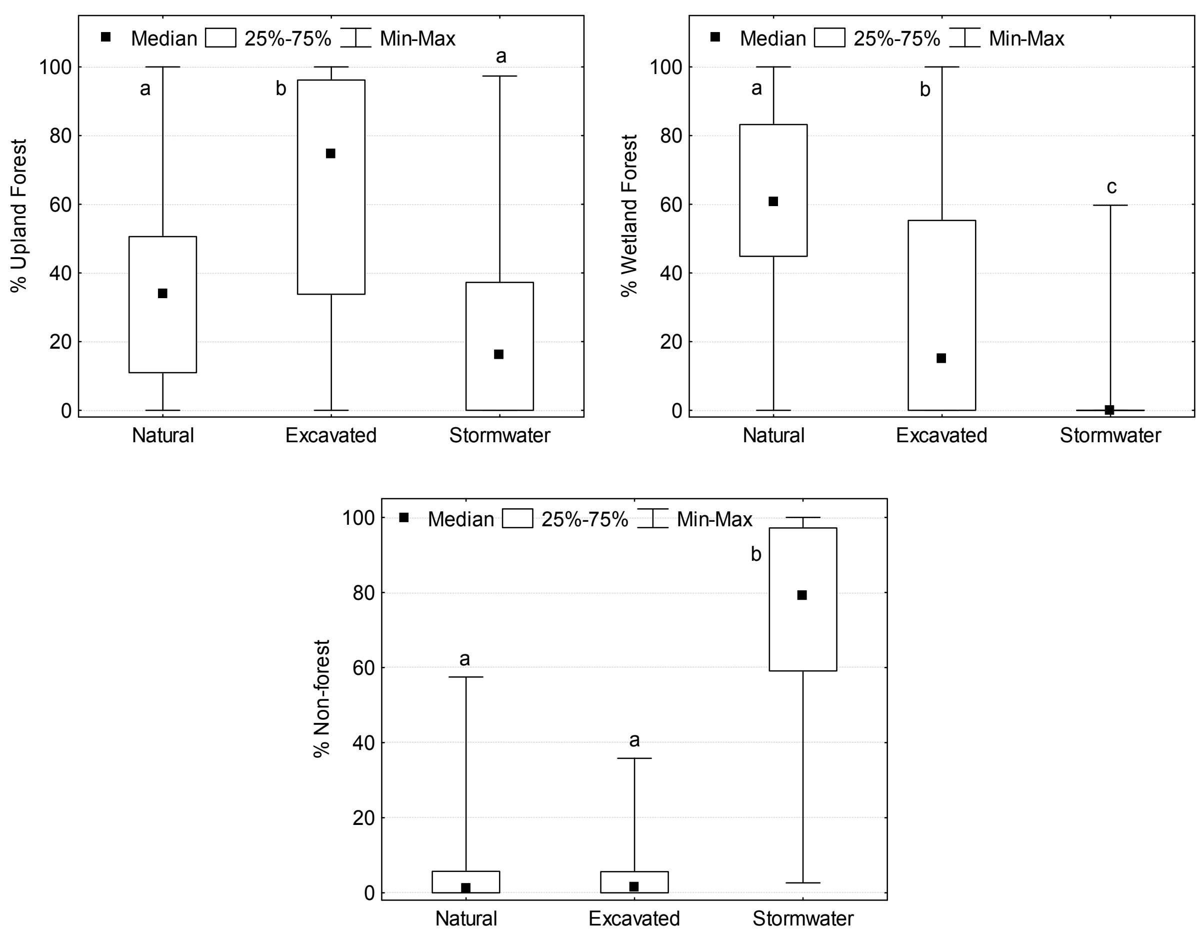

Figure 18. Percentage of surrounding upland forest, wetland forest, and non-forest for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the New Jersey Pinelands. Different letters indicate significant differences between wetland types.

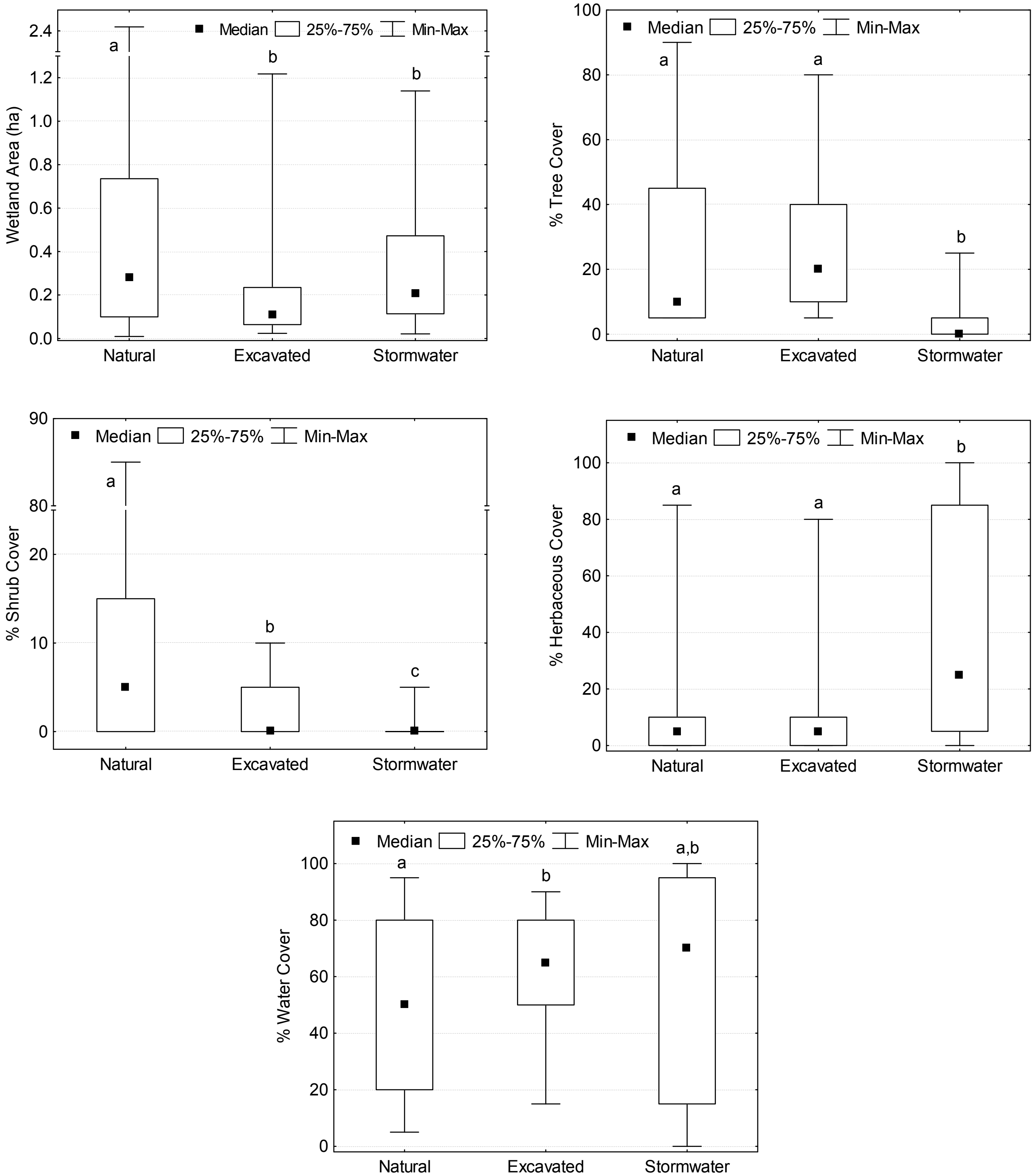

Figure 19. Wetland area and the percentage of tree, shrub, herbaceous vegetation, and water cover for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the New Jersey Pinelands. Different letters indicate significant differences between wetland types.

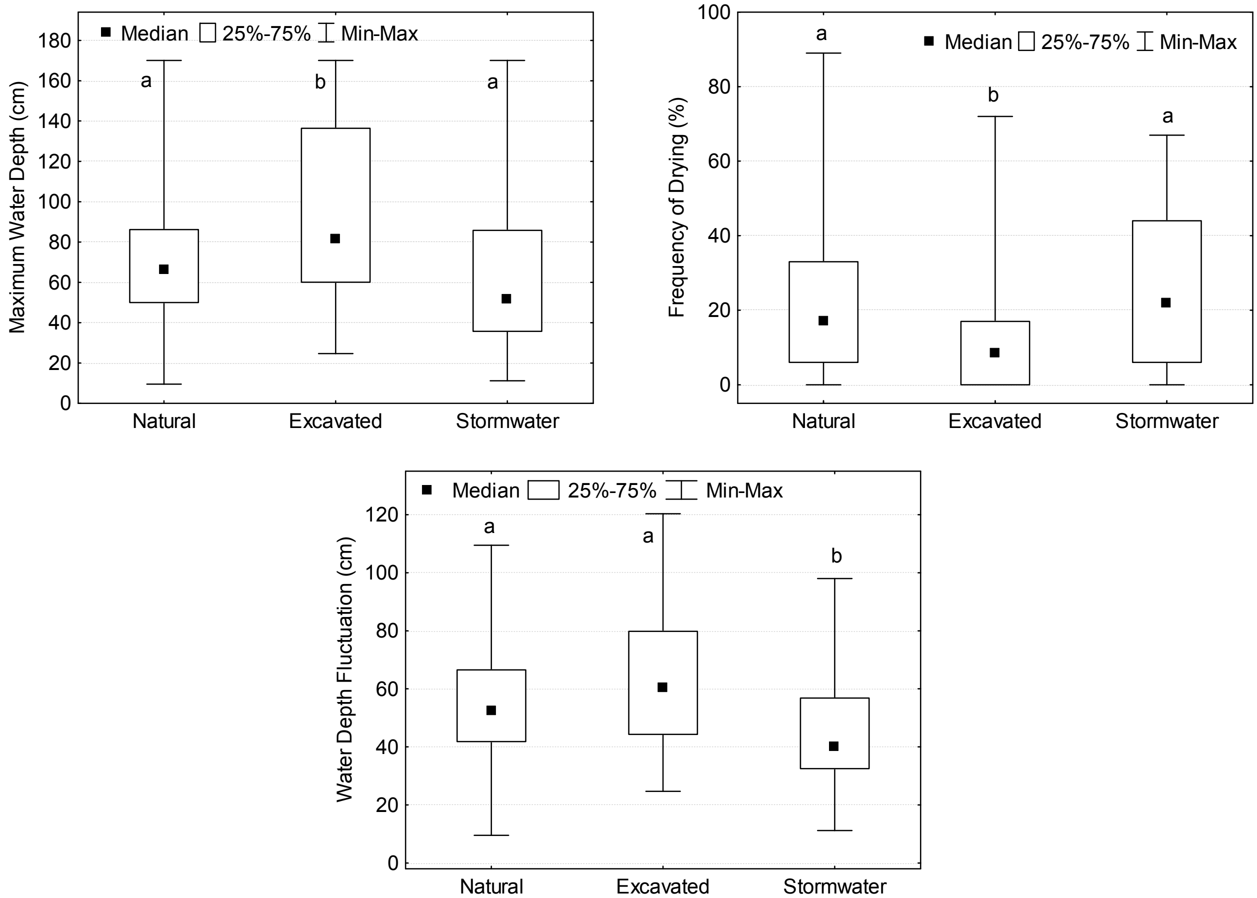

Figure 20. Water depth, frequency of drying, and water depth fluctuation for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the New Jersey Pinelands. Different letters indicate significant differences between wetland types.

Vegetation Inventory. We found 331 plant species (Table 7) at the 197 study sites. The number of species per site ranged from 4 to 51 with a mean (±1 SD) of 20.7 ± 9.5. Most of the species could be assigned to a specific biogeographic group, resulting in 71 Pine Barrens, 81 wide-ranging, 109 non-native, and 49 introduced species. Twenty-one species could not be assigned to any biogeographic group using Stone (1911) because these species were not listed, nomenclature at the time was uncertain, or a classification could not be definitively determined from the species accounts. We refer to these species as unclassified species. Twenty-seven plant species found at the study sites are considered endangered or species of concern in New Jersey (NJDEP 2016, Table 7). Twelve of the introduced plants found in our study are listed by Snyder and Kaufman (2004) as invasive, nonindigenous species in New Jersey.

Vegetation Assemblages. Based on the MRPP analysis of presence-absence data, we found a significant difference in plant assemblages between the three wetland types. Post-hoc MRPP comparisons revealed assemblage differences among all three wetland types (Table 8). Based on ANOVAs, we observed a significant difference in plant species richness and the percentage of Pine Barrens, wide-ranging, non-native, introduced, and unclassified species among the three wetland types (Table 8, Figure 22). Post-hoc tests indicated that natural ponds contained fewer plant species than excavated ponds and stormwater basins, which did not differ from

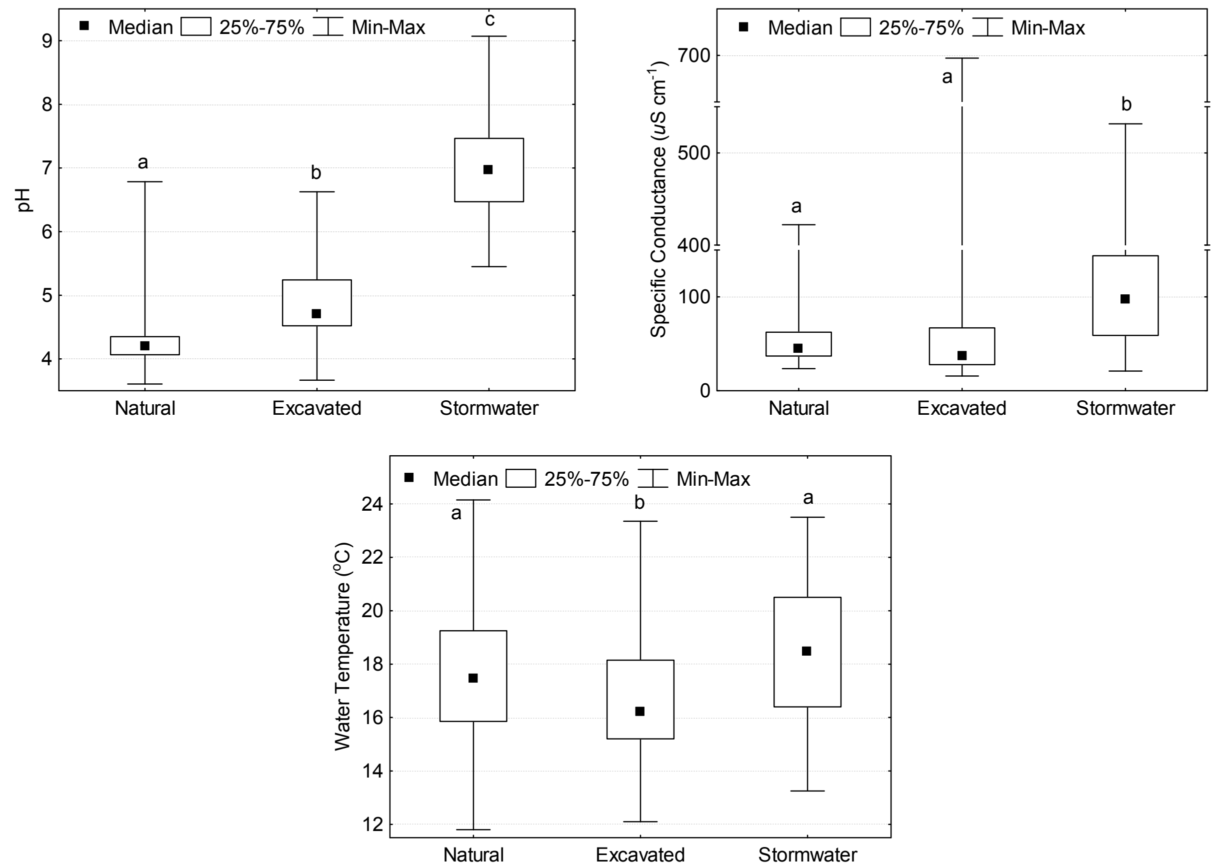

Figure 21. Box plots showing pH, specific conductance, and water temperature for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins. Different letters indicate significant differences between wetland types.

each other. Post-hoc tests also revealed that the percentage of Pine Barrens species and wide-ranging species were greater and the percentage of non-native species, introduced species, and unclassified species were lower for natural and excavated ponds compared to stormwater basins. The only difference observed for these species groups between natural and excavated ponds was that the percentage of non-native species was lower in natural compared to excavated ponds.

Plant species listed as endangered or species of concern in New Jersey were found in all three wetland types. Thirteen of these listed species were found in natural ponds, 12 in excavated ponds, and nine in stormwater basins. In natural and excavated ponds, most of these listed species were native Pine Barrens and wide-ranging species, whereas in stormwater basins, most of the listed species were not native to the Pinelands region (Figure 23).

Dominant herbaceous plants recorded at the study sites included Pine Barrens, wide-ranging, non-native, introduced, and unclassified species (Figure 24). Although not statistically tested, dominant plants found at natural ponds and excavated ponds were characterized by a relatively high percentage of Pine Barrens and wide-ranging species, a low percentage of non-native species, and no introduced or unclassified species. In contrast, stormwater basins were frequently dominated by non-native, introduced, and unclassified species.

Table 7. Frequency of occurrence of plant species classified as Pine Barrens, wide-ranging, non-native, and introduced (Stone 1911, USDA, NRCS 2018) at 99 natural ponds (NP), 52 excavated ponds (EP), and 46 stormwater basins (SB). With the exception of *Sphagnum* sp., a wide-ranging nonvascular taxa not listed in Stone (1911), species that could not be definitively placed in a biogeographic category were considered unclassified species. Endangered species (**) and species of concern (*) are based on NJDEP (2016); invasive species (‡) are based on Snyder and Kaufman (2004).

Biogeographic Group Scientific Name	NP	EP	SB	All	Scientific Name	NP	EP	SB	All
Pine Barrens Species									
Amphicarpum purshii	7	-	-	7	*Orontium aquaticum*	2	1	-	3
Betula populifolia	6	8	1	15	*Panicum rigidulum var. pubescens*	27	31	5	63
Brasenia schreberi	16	-	-	16	*Pinus rigida*	84	48	12	144
Carex exilis	1	-	-	1	*Polygala cruciata*	1	1	-	2
Carex striata	66	7	1	74	**Potamogeton confervoides*	-	3	-	3
Chamaecyparis thyoides	17	8	-	25	*Proserpinaca pectinata*	26	16	1	43
Chamaedaphne calyculata	50	12	-	62	*Quercus marilandica*	-	5	1	6
Cladium mariscoides	20	12	-	32	*Rhexia mariana*	-	1	-	1
Cyperus dentatus	5	9	8	22	*Rhododendron viscosum*	3	-	-	3
Cyperus retrorsus	1	-	-	1	*Rhynchospora alba*	9	6	-	15
Dichanthelium spretum	18	15	5	38	**Rhynchospora cephalantha*	1	-	-	1
Drosera filiformis	2	8	-	10	*Rhynchospora chalarocephala*	8	10	1	19
Eleocharis microcarpa	28	21	-	49	***Rhynchospora filifolia*	1	-	-	1
Eleocharis robbinsii	12	9	1	22	*Rhynchospora fusca*	6	8	-	14
Eleocharis tricostata	22	4	-	26	*Rhynchospora torreyana*	1	-	-	1
Eleocharis tuberculosa	2	6	-	8	*Sabatia difformis*	3	1	-	4
Eriocaulon aquaticum	-	5	-	5	*Saccharum giganteum*	5	3	-	8
Eriocaulon compressum	5	2	-	7	*Sagittaria engelmanniana*	3	3	-	6
Eupatorium album	-	-	1	1	*Sarracenia purpurea*	-	1	-	1
Eupatorium leucolepis	1	3	-	4	*Schoenoplectus subterminalis*	7	6	-	13
***Eupatorium resinosum*	-	1	-	1	*Scleria reticularis*	13	5	-	18
Gaylussacia dumosa	-	2	-	2	**Sclerolepis uniflora*	1	-	-	1
Hypericum denticulatum	3	-	-	3	*Sparganium americanum*	1	6	2	9
Ilex glabra	2	4	1	7	*Utricularia geminiscapa*	22	24	1	47
Itea virginica	1	-	-	1	**Utricularia inflata*	-	6	2	8
Juncus militaris	3	4	-	7	*Utricularia juncea*	-	1	-	1
Kalmia angustifolia	16	8	-	24	**Utricularia purpurea*	10	4	-	14
Lachnanthes caroliniana	4	12	-	16	**Utricularia radiata*	2	1	-	3
**Lobelia canbyi*	5	1	-	6	*Utricularia striata*	37	6	-	43
Lobelia nuttallii	1	1	1	3	*Utricularia subulata*	10	5	-	15
Lycopodiella alopecuroides	-	6	-	6	*Vaccinium corymbosum*	71	16	1	88
Lycopodiella appressa	-	3	-	3	*Vaccinium macrocarpon*	15	24	1	40
Lyonia mariana	20	7	-	27	*Xyris difformis*	22	21	5	48
**Muhlenbergia torreyana*	8	2	-	10	***Xyris fimbriata*	1	-	-	1
Muhlenbergia uniflora	-	4	-	4	*Xyris smalliana*	14	4	-	18
Nuphar lutea ssp. variegata	5	8	1	14					
Wide-ranging Species									
Acer rubrum	92	44	14	150	*Andropogon virginicus*	12	18	5	35
Agalinis purpurea	1	-	-	1	*Aristida longespica*	-	2	-	2
Agrostis hyemalis	-	-	2	2	*Aronia arbutifolia*	4	2	-	6
Amelanchier canadensis	-	1	-	1	*Bartonia virginica*	2	1	-	3
Andropogon glomeratus	-	5	1	6	*Cephalanthus occidentalis*	19	6	1	26

Table 7. Continued.

Biogeographic Group Scientific Name	NP	EP	SB	All	Scientific Name	NP	EP	SB	All
Wide-ranging Species (cont'd)									
Clethra alnifolia	20	-	-	20	*Nuttallanthus canadensis*	-	-	1	1
**Coreopsis rosea*	2	1	-	3	*Nymphaea odorata*	37	15	1	53
Cyperus flavescens	-	-	1	1	**Nymphoides cordata*	3	1	-	4
Decodon verticillatus	21	4	2	27	*Nyssa sylvatica*	72	31	3	106
Diodia teres	-	1	8	9	*Osmunda cinnamomea*	1	1	1	3
Drosera intermedia	36	26	1	63	*Osmunda regalis*	2	2	-	4
Drosera rotundifolia	-	2	1	3	*Panicum verrucosum*	56	26	1	83
**Elatine americana*	-	-	1	1	*Panicum virgatum*	26	29	6	61
Eleocharis olivacea	32	7	-	39	*Paspalum setaceum*	-	1	-	1
Epilobium coloratum	-	-	1	1	*Polygala nuttallii*	-	1	-	1
Eriophorum virginicum	1	-	-	1	*Populus grandidentata*	-	4	1	5
Eubotrys racemosa	29	9	-	38	*Quercus alba*	11	14	5	30
Eupatorium hyssopifolium	-	-	1	1	*Quercus coccinea*	2	11	1	14
Euthamia caroliniana	8	15	8	31	*Quercus montana*	-	3	2	5
Fimbristylis autumnalis	8	4	1	13	*Quercus stellata*	-	5	1	6
Gaylussacia baccata	1	1	-	2	*Quercus velutina*	1	10	1	12
Gaylussacia frondosa	2	5	-	7	*Rhexia virginica*	26	15	2	43
Glyceria obtusa	-	1	-	1	*Rhynchospora capitellata*	2	10	2	14
Gratiola aurea	6	13	3	22	**Rhynchospora inundata*	4	-	-	4
Hypericum canadense	10	10	5	25	*Rhynchospora macrostachya*	4	-	-	4
Hypericum gentianoides	-	-	1	1	*Rubus hispidus*	-	-	1	1
Hypericum hypericoides	-	-	2	2	*Sassafras albidum*	11	17	1	29
Iris prismatica	3	-	-	3	*Schoenoplectus pungens*	-	1	7	8
Juncus canadensis	19	19	5	43	*Scirpus cyperinus*	22	26	33	81
Juncus debilis	5	10	1	16	*Smilax glauca*	3	-	-	3
Juncus effusus	3	9	26	38	*Smilax rotundifolia*	53	12	2	67
Juncus pelocarpus	21	26	5	52	*Sphagnum sp.*	93	36	7	136
Juncus tenuis	-	1	7	8	*Spiranthes cernua*	-	1	-	1
Ludwigia alternifolia	1	3	4	8	*Symphyotrichum novi-belgii*	1	3	2	6
Ludwigia sphaerocarpa	1	2	-	3	*Triadenum virginicum*	14	9	3	26
Lyonia ligustrina	-	1	1	2	**Utricularia gibba*	-	1	-	1
Lysimachia terrestris	-	1	-	1	*Viola lanceolata*	7	14	4	25
Magnolia virginiana	7	1	1	9	*Woodwardia areolata*	1	-	1	2
Melampyrum lineare	-	1	-	1	*Woodwardia virginica*	50	3	-	53
Morella pensylvanica	-	1	1	2	*Xyris torta*	3	-	-	3
Myriophyllum humile	3	11	2	16					
Non-native Species									
Acalypha rhomboidea	-	-	5	5	*Boehmeria cylindrica*	-	1	-	1
Acer saccharinum	-	1	11	12	*Callitriche heterophylla*	-	-	2	2
**Alopecurus carolinianus*	-	-	2	2	*Campsis radicans*	-	1	1	2
Ambrosia artemisiifolia	-	1	1	2	**Carex caroliniana*	-	-	1	1
Asclepias syriaca	-	-	2	2	*Carex lurida*	1	-	6	7
Baccharis halimifolia	-	-	1	1	*Carex scoparia*	-	-	1	1
Betula nigra	-	1	1	2	*Carex stipata*	-	-	1	1
Bidens connata	-	1	1	2	*Carex tribuloides*	-	-	3	3
Bidens frondosa	2	5	4	11	*Catalpa bignonioides*	-	1	1	2

Table 7. Continued.

Biogeographic Group Scientific Name	NP	EP	SB	All	Scientific Name	NP	EP	SB	All
Non-native Species (cont'd)									
Chamaesyce maculata	-	-	5	5	*Paspalum laeve*	-	-	6	6
Chasmanthium laxum	-	1	-	1	*Peltandra virginica*	1	-	-	1
Cornus amomum	-	-	1	1	*Phalaris arundinacea*	1	1	7	9
Cornus florida	-	1	-	1	*Phragmites australis*	4	9	21	34
Cyperus strigosus	-	-	12	12	*Pilea pumila*	-	-	1	1
Dichanthelium clandestinum	-	1	2	3	*Pinus strobus*	-	1	5	6
**Dichanthelium wrightianum*	2	-	-	2	*Pinus virginiana*	-	1	4	5
***Diodia virginiana*	-	-	1	1	*Plantago aristata*	-	-	3	3
Dioscorea villosa	-	-	1	1	*Plantago virginica*	-	-	1	1
Diospyros virginiana	13	5	1	19	*Platanus occidentalis*	-	3	2	5
Dulichium arundinaceum	33	12	2	47	*Polygonum arifolium*	-	-	1	1
Eclipta prostrata	-	-	9	9	*Polygonum hydropiperoides*	4	3	20	27
Eleocharis acicularis	3	-	4	7	*Polygonum lapathifolium*	-	-	3	3
Eleocharis obtusa	3	4	24	31	*Polygonum punctatum*	1	3	17	21
Eleocharis palustris	-	-	3	3	*Polygonum sagittatum*	-	-	4	4
**Eleocharis quadrangulata*	-	-	4	4	*Potamogeton diversifolius*	-	3	14	17
Equisetum arvense	-	-	1	1	*Potamogeton pusillus*	-	-	2	2
Erechtites hieraciifolius	2	3	7	12	*Potentilla norvegica*	-	-	1	1
Erigeron annuus	-	-	1	1	*Proserpinaca palustris*	-	1	-	1
Eupatorium perfoliatum	-	-	2	2	*Prunella vulgaris*	-	-	3	3
Eutrochium dubium	-	-	1	1	*Prunus serotina*	-	1	5	6
Festuca rubra	-	-	1	1	*Quercus bicolor*	1	-	-	1
Galium tinctorium	1	1	9	11	*Quercus falcata*	1	8	1	10
Hibiscus moscheutos	-	-	4	4	*Quercus phellos*	13	14	2	29
**Hydrocotyle verticillata*	-	-	1	1	*Rorippa palustris*	-	-	11	11
Hypericum mutilum	6	10	6	22	*Sagittaria latifolia*	-	1	-	1
Ilex opaca	2	7	1	10	*Salix nigra*	-	6	26	32
Juglans nigra	-	2	-	2	*Sambucus nigra ssp. canadensis*	-	-	1	1
Juncus bufonius	-	-	1	1	**Schoenoplectiella smithii*	-	-	1	1
Juncus marginatus	-	-	1	1	*Schoenoplectus tabernaemontani*	-	-	6	6
Juncus scirpoides	-	2	1	3	*Sisyrinchium angustifolium*	-	-	4	4
Juniperus virginiana	-	4	5	9	*Solanum carolinense*	-	-	2	2
Leersia oryzoides	6	8	17	31	*Solidago altissima*	-	-	2	2
Lemna sp.	-	3	8	11	*Spiraea tomentosa*	-	-	1	1
Lindernia dubia	1	2	18	21	*Spirodela polyrrhiza*	-	1	-	1
Liquidambar styraciflua	37	19	4	60	*Symphyotrichum racemosum*	-	1	7	8
Ludwigia palustris	3	7	40	50	*Thelypteris palustris*	1	1	-	2
Lycopus uniflorus	2	2	4	8	*Torreyochloa pallida*	1	-	-	1
Lycopus virginicus	-	3	9	12	*Toxicodendron radicans*	-	-	3	3
Mikania scandens	-	-	4	4	*Typha angustifolia*	1	1	13	15
Onoclea sensibilis	-	-	5	5	*Typha latifolia*	-	1	25	26
Panicum dichotomiflorum	-	-	10	10	*Ulmus americana*	-	1	-	1
**Panicum hemitomon*	2	-	-	2	***Utricularia resupinata*	-	1	-	1
Panicum philadelphicum	1	1	-	2	*Veronica peregrina*	-	-	6	6
Panicum rigidulum var. rigidulum	-	-	12	12	*Wolffia brasiliensis*	-	-	2	2
Parthenocissus quinquefolia	1	-	2	3					

Table 7. Continued.

Biogeographic Group Scientific Name	NP	EP	SB	All	Scientific Name	NP	EP	SB	All
Introduced Species									
‡Acer platanoides	-	1	-	1	*Morus alba*	-	-	5	5
Agrostis gigantea	-	-	2	2	*Picea abies*	-	-	1	1
‡Ailanthus altissima	-	1	1	2	*Plantago lanceolata*	-	-	7	7
Anthoxanthum odoratum	-	-	2	2	*Poa annua*	-	-	1	1
Artemisia vulgaris	-	-	1	1	*Poa pratensis*	-	-	2	2
‡Berberis thunbergii	-	-	1	1	*Polygonum aviculare*	-	-	6	6
‡Celastrus orbiculatus	-	-	1	1	*Polygonum cespitosum*	-	1	4	5
Cerastium fontanum	-	-	1	1	*Polygonum hydropiper*	-	-	7	7
‡Cirsium arvense	-	-	1	1	*Polygonum minus*	-	-	15	15
Commelina communis	-	-	1	1	*‡Polygonum perfoliatum*	-	-	2	2
Cyperus amuricus	-	-	8	8	*Polygonum persicaria*	-	-	8	8
Cyperus difformis	-	-	8	8	*Portulaca oleracea*	-	-	2	2
Cyperus esculentus	-	-	3	3	*Pyrus calleryana*	-	-	4	4
Cyperus iria	-	-	4	4	*Ranunculus sardous*	-	-	4	4
Echinochloa crus-galli	1	-	24	25	*‡Rosa multiflora*	-	-	3	3
Egeria densa	-	-	1	1	*Rumex crispus*	-	-	15	15
‡Elaeagnus umbellata	-	-	2	2	*Schoenoplectiella mucronata*	-	-	1	1
Eragrostis pilosa	-	-	4	4	*Scleranthus annuus*	-	-	1	1
‡Lespedeza cuneata	-	-	3	3	*Taraxacum officinale*	-	-	2	2
‡Lonicera japonica	-	1	-	1	*Trifolium arvense*	-	-	2	2
Lotus corniculatus	-	-	2	2	*Trifolium dubium*	-	-	4	4
‡Lythrum salicaria	-	-	4	4	*Trifolium repens*	-	-	1	1
Mazus pumilus	-	-	3	3	*Veronica persica*	-	-	1	1
‡Microstegium vimineum	1	-	7	8	*Viola arvensis*	-	-	1	1
Miscanthus sinensis	-	-	2	2					
Unclassified Species									
Agrostis scabra	-	1	-	1	*Erigeron philadelphicus*	-	-	1	1
Apocynum cannabinum	-	2	22	24	*Eupatorium serotinum*	-	-	6	6
Carex annectens	-	-	10	10	*Gratiola neglecta*	-	-	3	3
Carex longii	1	1	24	26	*Juncus acuminatus*	-	1	18	19
Cuscuta sp.	2	-	1	3	***Juncus diffusissimus*	-	-	5	5
Cyperus acuminatus	-	-	2	2	*Kyllinga gracillima*	-	-	5	5
Cyperus flavicomus	-	-	1	1	*Ludwigia peploides*	-	-	2	2
Cyperus odoratus	1	-	-	1	*Polygonum pensylvanicum*	-	-	17	17
***Dichanthelium hirstii*	-	1	-	1	*Populus deltoides*	-	2	5	7
Echinochloa muricata	1	-	2	3	*Triodanis biflora*	-	-	1	1
Eleocharis tenuis	3	-	7	10					

Table 8. Post-hoc test results from Multi-response Permutation Procedures (MRPP) using presence-absence (PA) and relative-abundance (RA) taxa-assemblage data and from analysis of variance (ANOVA) using frequency of occurrence of biogeographic groups between natural ponds (NP), excavated ponds (EP), and stormwater basins (SB). The N for each wetland type is in parentheses and varies by taxa. Only significant p-values are given, ns = not significant.

		Post-hoc Test Results		
Taxa Assemblages and Biogeographic Groups	MRPP or ANOVA	Natural vs. Excavated	Excavated vs. Stormwater	Natural vs. Stormwater
Vegetation (NP=99, EP=52, SB=46)				
Plant assemblages (PA)	<0.001	<0.001	<0.001	<0.001
Plant species richness	0.003	0.026	ns	0.017
Pine Barrens plant species	<0.001	ns	<0.001	<0.001
% Wide-ranging plant species	<0.001	ns	<0.001	<0.001
% Non-native plant species	<0.001	0.011	<0.001	<0.001
% Introduced plant species	<0.001	ns	<0.001	<0.001
% Unclassified plant species	<0.001	ns	<0.001	<0.001
Adult Anurans (NP=99, EP=52, SB=44)				
Anuran assemblages (PA)	<0.001	<0.001	<0.001	<0.001
Anuran assemblages (RA)	<0.001	<0.001	<0.001	<0.001
Anuran species richness	<0.001	ns	<0.001	<0.001
% Pine Barrens anuran species	<0.001	0.003	<0.001	<0.001
% Wide-ranging anuran species	0.033	ns	ns	ns
% Non-native anuran species	0.003	ns	ns	0.006
Tadpoles (NP=33, EP=32, SB=18)				
Tadpole Assemblages (PA)	<0.001	0.037	<0.001	<0.001
Tadpole species richness	ns	ns	ns	ns
% Pine Barrens tadpole species	<0.001	ns	0.010	<0.001
% Wide-ranging tadpole species	0.007	ns	0.022	0.003
% Non-native tadpole species	<0.001	ns	<0.001	<0.001
Fish (NP=14, EP=15, SB=7)				
Fish assemblages (PA)	0.002	ns	<0.012	<0.001
Fish species richness	0.003	ns	ns	ns
% Pine Barrens fish species	0.016	ns	0.024	ns
% Wide-ranging fish species	0.022	ns	ns	0.045
% Non-native fish species	0.002	ns	0.043	0.020
Number of significant differences		7	17	19

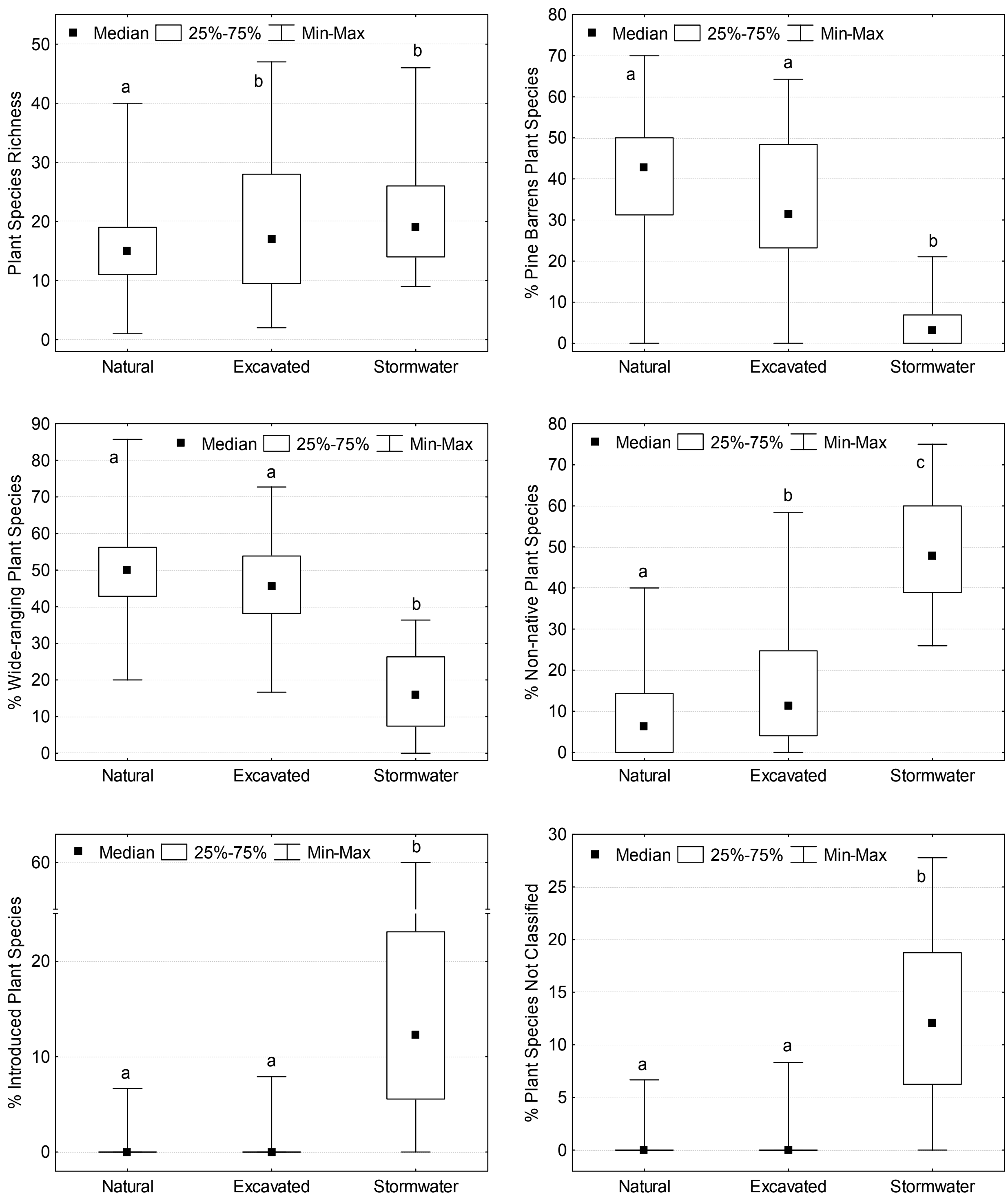

Figure 22. Plant species richness and the percentage of Pine Barrens, wide-ranging, non-native, introduced, and unclassified species for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the Pinelands. Different letters indicate significant differences between wetland types.

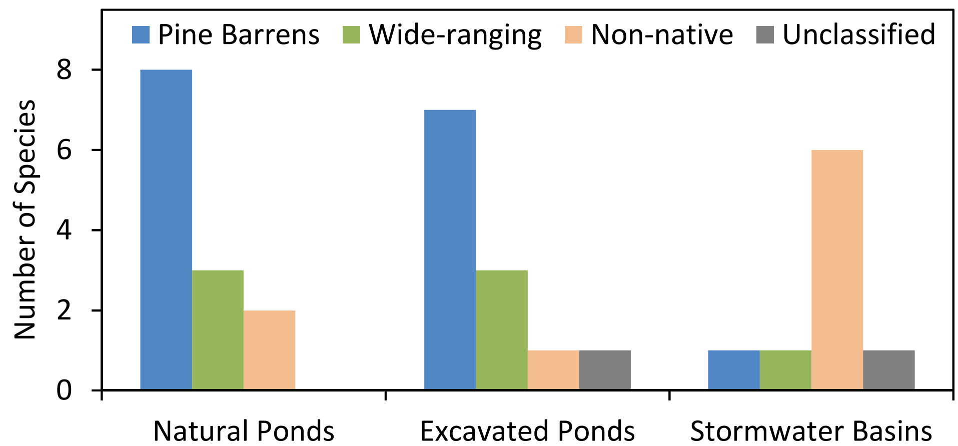

Figure 23. Number of New Jersey endangered species or species of concern that are Pine Barrens, wide-ranging, non-native, and unclassified in 99 natural ponds, 52 excavated ponds, and 46 stormwater basins.

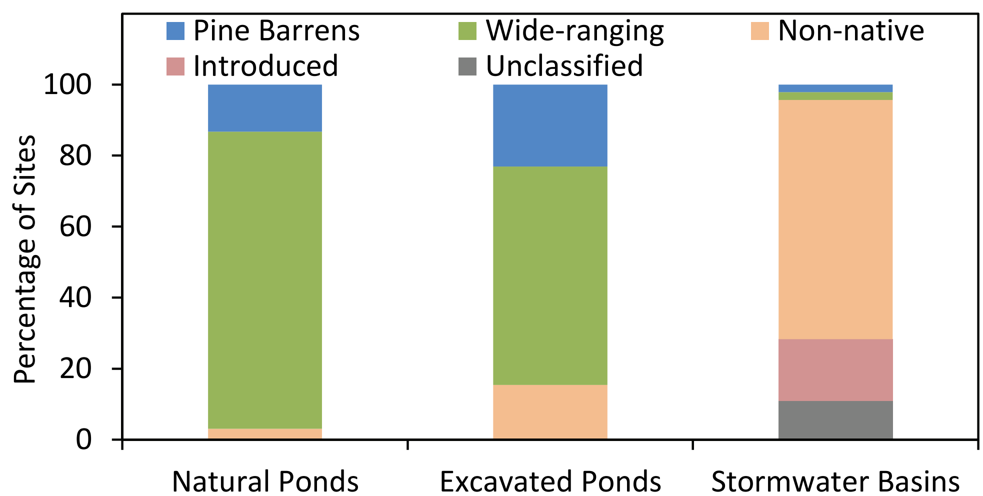

Figure 24. Percentage of dominant plant species that are Pine Barrens, wide-ranging, non-native, and unclassified in 99 natural ponds, 52 excavated ponds, and 46 stormwater basins.

Anuran Inventory. We heard anurans calling from 195 of the 197 wetlands. The two wetlands with no calling anurans were stormwater basins. At the remaining 195 wetlands, we heard a total of 12 frog species and two toad species (Table 9). The number of species heard per site ranged from 1 to 9 with a mean of 4.5 (±1.9). A minimum of 6,412 anurans were heard calling at the 195 wetlands. This number is conservative because, as previously mentioned, the maximum number of individuals counted for a species during a visit was limited to ten or fewer.

Two of the 14 anuran species heard calling were Pine Barrens species, five were wide-ranging species, six were non-native species, and one species was not classified by Conant (1979, Table 9). The unclassified species was the Atlantic Coast leopard frog (*Rana kauffeldi*), which was only recently described (Feinberg and others 2014). We excluded the Atlantic Coast leopard frog from further analysis because we only heard a single individual at one excavated pond, it is an uncommon species in the Pinelands (Zampella and others 2001, 2003, 2005, 2006), and it is not usually heard at the types of wetlands that we studied (Schlesinger and others 2017). Natural and excavated ponds both supported the threatened Pine Barrens treefrog, which is a Pine Barrens species, whereas excavated ponds and stormwater basins both supported the endangered southern gray treefrog, which is a non-native species (Table 9).

Table 9. Frequency of occurrence (%) of vocalizing anuran species classified as Pine Barrens, wide-ranging, and non-native at 99 natural ponds, 52 excavated ponds, and 46 stormwater basins. Biogeographic classification is from Conant (1979) and nomenclature follows SSAR (2017). Species listed as threatened (*) or endangered (**) in New Jersey are based on https://www.nj.gov/dep/fgw/tandespp.htm.

Biogeographic Group Scientific Name	Common Name	Natural Ponds N=99	Excavated Ponds N=52	Stormwater Basins N=46	All Wetland Types N=197
Pine Barrens Species					
Lithobates virgatipes	carpenter frog	39	23	-	26
**Hyla andersonii*	Pine Barrens treefrog	66	35	-	42
Wide-ranging Species					
Scaphiopus holbrookii	eastern spadefoot	-	-	2	1
Anaxyrus fowleri	Fowler's toad	14	33	57	29
Lithobates sphenocephalus	southern leopard frog	79	54	11	56
Lithobates clamitans	green frog	67	79	35	62
Pseudacris crucifer	spring peeper	94	94	74	89
Non-native Species					
Acris crepitans	northern cricket frog	1	2	4	2
***Hyla chrysoscelis*	southern gray treefrog	-	4	15	5
Pseudacris kalmi	New Jersey chorus frog	24	25	7	20
Lithobates catesbeianus	bullfrog	21	31	33	26
Hyla versicolor	northern gray treefrog	34	54	52	44
Lithobates sylvaticus	wood frog	66	46	15	49

Anuran Assemblages. MRPP results indicated a significant difference in anuran assemblages between wetland types using both presence-absence data and relative-abundance data. Post-hoc MRPP comparisons using both presence-absence and relative-abundance data revealed differences between all three wetland types (Table 8). Based on ANOVAs, we observed a

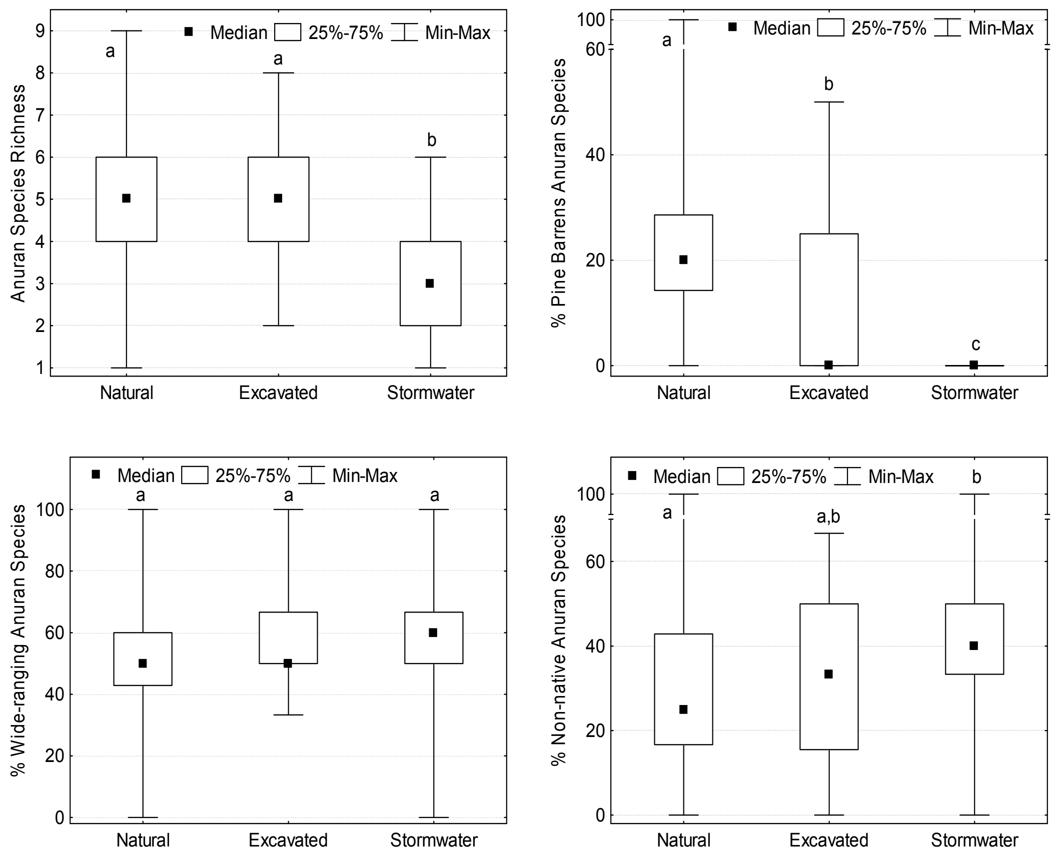

Figure 25. Anuran species richness and the percentage of Pine Barrens, wide-ranging, and non-native species for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the Pinelands. Different letters indicate significant differences between wetland types.

significant difference in anuran species richness between wetland types with both natural and excavated ponds supporting a greater number of species compared to stormwater basins (Figure 25). We also found a significant difference in the percentage of Pine Barrens species and non-native species between wetland types. Post-hoc tests indicated that the percentage of Pine Barrens species was greater for natural ponds compared to excavated ponds. Pine Barrens species were not heard calling from any stormwater basin. Post-hoc tests also indicated that stormwater basins supported a greater percentage of non-native species than natural ponds.

Tadpole Inventory. We collected tadpoles from 83 wetlands (32 natural ponds, 33 excavated ponds, and 18 stormwater basins). A total of 10 frog species and one toad species were identified from the 83 wetlands (Table 10). The number of species heard per site ranged from 1 to 4 with a mean of 2.0 (±0.9). Two of the 11 species collected were Pine Barrens species, four were wide-ranging species, and five were non-native species.

Tadpole Assemblages. Based on the MRPP analysis using presence-absence data, we found a significant difference in tadpole assemblages between wetland types. Post-hoc MRPP comparisons revealed differences in tadpole assemblages between natural ponds and

Table 10. Frequency of occurrence (%) of tadpoles species classified as Pine Barrens, wide-ranging, and non-native at 33 natural pond, 32 excavated ponds, and 18 stormwater basins. Biogeographic classification is from Conant (1979) and nomenclature follows SSAR (2017). Species listed as threatened (*) in New Jersey are based on https://www.nj.gov/dep/fgw/tandespp.htm.

Biogeographic Group Scientific Name	Common Name	Natural Ponds N=33	Excavated Ponds N=32	Stormwater Basins N=18	All Wetland Types N=83
Pine Barrens Species					
**Hyla andersonii*	Pine Barrens treefrog	16	15	-	19
Lithobates virgatipes	carpenter frog	41	21	-	49
Wide-ranging Species					
Anaxyrus fowleri	Fowler's toad	-	-	28	-
Pseudacris crucifer	spring peeper	6	12	6	8
Lithobates sphenocephalus	southern leopard frog	28	24	6	34
Lithobates clamitans	green frog	63	70	39	75
Non-native Species					
Acris crepitans	northern cricket frog	-	3	-	-
Lithobates palustris	pickerel frog	-	-	6	-
Lithobates catesbeianus	bullfrog	6	27	72	8
Hyla versicolor	northern gray treefrog	6	36	61	8
Lithobates sylvaticus	wood frog	9	3	6	11

stormwater basins and excavated ponds and stormwater basins (Table 8). ANOVAs indicated no difference in tadpole species richness between wetland types. We observed a significant difference in the percentage of Pine Barrens species, wide-ranging species, and non-native species between wetland types (Figure 26). Post-hoc tests indicated that the percentage of Pine Barrens species was similar in natural and excavated ponds, but, as with adult anurans, Pine Barrens tadpole species were not found in any stormwater basin. Post-hoc tests also revealed that the percentage of wide-ranging species was greater in natural and excavated ponds compared to stormwater basins and the percentage of non-native species was greater in stormwater basins compared to natural and excavated ponds.

Fish Inventory. We collected a total of 2,211 individual fish, representing 14 species, from the 36 wetlands surveyed for fish (14 natural ponds, 15 excavated ponds, and seven stormwater basins, Table 11). The number of species collected per site ranged from 1 to 5 with a mean of 1.9 (±1.0). Of the 14 fish species collected, three species were classified as Pine Barrens species, four as wide-ranging species, and seven as non-native species.

Fish Assemblages. The MRPP analysis using presence-absence data indicated a significant difference in fish assemblages between the three wetland types. Post-hoc MRPP comparisons revealed differences between natural ponds and stormwater basins and excavated ponds and stormwater basins (Table 8). Based on ANOVA results, fish species richness differed between wetland types and stormwater basins appeared to support the greatest number of fish species (Figure 27), but none of the post-hoc test results were significant (Table 8). We also observed a difference in the percentage of Pine Barrens, wide-ranging, and non-native fish species

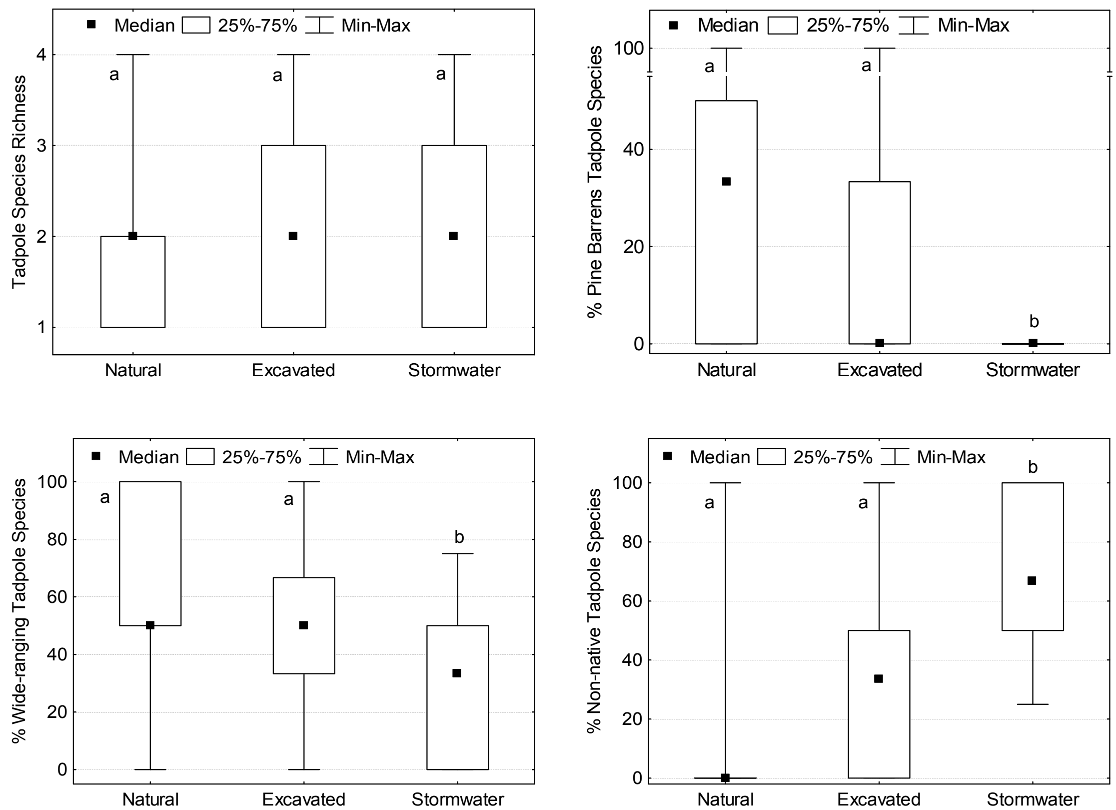

Figure 26. Tadpole species richness and the percentage of Pine Barrens, wide-ranging, and non-native species for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the Pinelands. Different letters indicate significant differences between wetland types.

Table 11. Frequency of occurrence (%) of fish species classified as Pine Barrens, wide-ranging, and non-native at 14 natural ponds, 15 excavated ponds, and 7 stormwater basins. Biogeographic classification is from Hastings (1984). Fish nomenclature follows Fuller et al. (1999).

Biogeographic Group Scientific Name	Common Name	Natural Ponds N=14	Excavated Ponds N=15	Stormwater Basins N=7	All Wetland Types N=36
Pine Barrens Species					
Enneacanthus chaetodon	blackbanded sunfish	-	7	-	3
Acantharcus pomotis	mud sunfish	-	7	-	3
Enneancanthus obesus	banded sunfish	43	53	14	42
Wide-ranging Species					
Anguilla rostrata	American eel	-	-	14	3
Esox niger	chain pickerel	-	7	14	6
Esox americanus	redfin pickerel	21	-	-	8
Umbra pygmaea	eastern mudminnow	93	67	29	69
Non-native Species					
Fundulus diaphanus	banded killifish	-	-	14	3
Lepomis cyanellus	green sunfish	-	-	14	3
Ameiurus nebulosus	brown bullhead	-	7	14	6
Micropterus salmoides	largemouth bass	-	-	29	6
Gambusia spp.	mosquitofish species	-	-	43	8
Lepomis gibbosus	pumpkinseed	-	7	57	14
Lepomis macrochirus	bluegill	-	7	57	14

between wetland types. Post-hoc tests revealed that the percentage of Pine Barrens species was greatest in excavated ponds compared to stormwater basins, the percentage of wide-ranging species was greater in natural ponds compared to stormwater basins, and the percentage of non-native species was greater in stormwater basins compared to both natural and excavated ponds (Figure 27). Non-native fish were absent from natural ponds, whereas four species of non-native fish were found only at stormwater basins (Table 11).

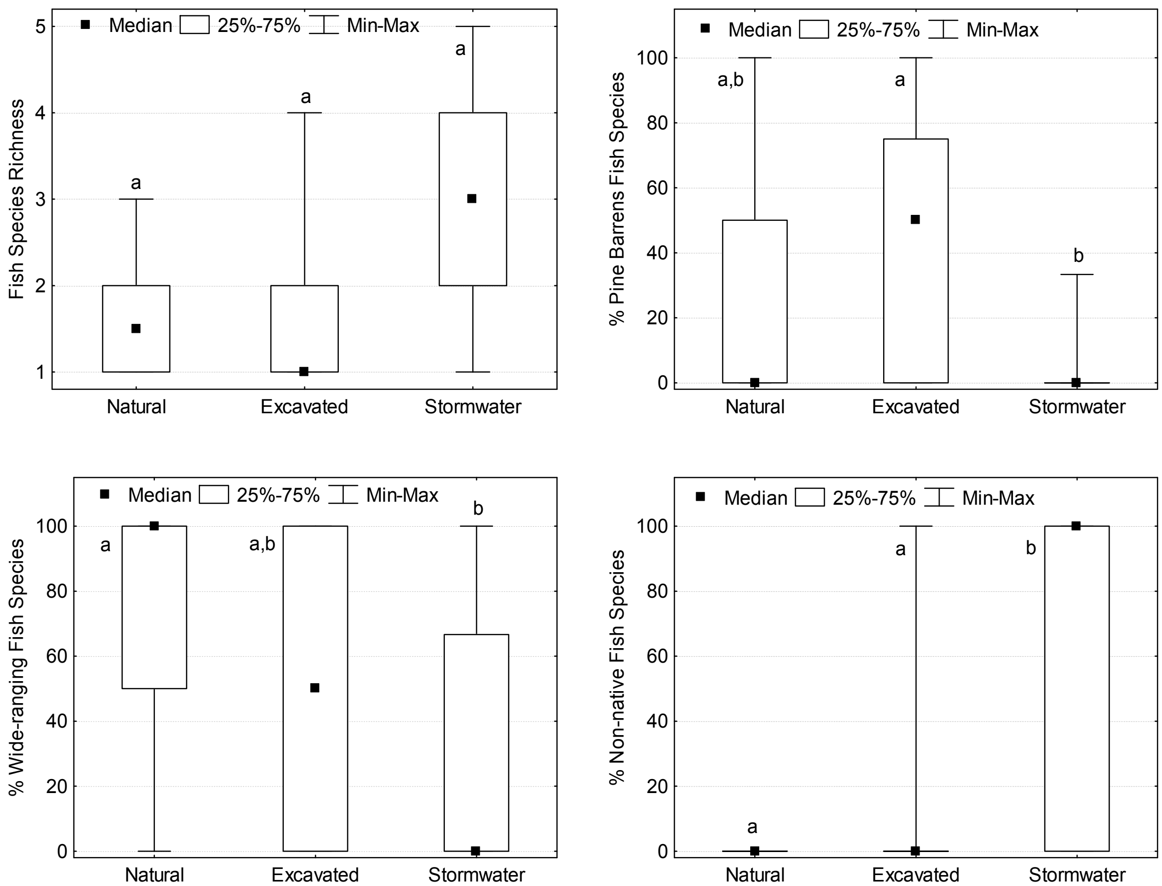

Figure 27. Fish species richness and the percentage of Pine Barrens, wide-ranging, and non-native species for 99 natural ponds, 52 excavated ponds, and 46 stormwater basins in the Pinelands. Different letters indicate significant differences between wetland types.

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