Prioritizing Non-regulatory Protection of Vernal Pools in the Queen's River Watershed, Rhode Island

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Final Research Report

Prepared for

RI Department of Environmental Management

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EXECUTIVE SUMMARY

Background

Vernal pools are widely recognized as critical habitat for a variety of vertebrate and invertebrate animals. In forested regions of New England, most of these wetlands hold water from a few weeks to several months each year; some dry only once in several years. Within Rhode Island, vernal pools provide essential breeding sites for a number of amphibians, such as the wood frog (*Rana sylvatica*) and the spotted salamander (*Ambystoma maculatum*), which require extensive upland forest habitat outside of the breeding season.

Recently, protecting vernal pools from anthropogenic impacts has become a major conservation and regulatory goal throughout the United States. However, these valuable wetlands are increasingly at risk as a result of their small size, periodic drying, and isolated nature, all of which may make them difficult to identify and protect. Although wetland regulations in some states offer protection for vernal pools, they do not address terrestrial habitat requirements of pool-breeding amphibians, which are equally important for long-term population maintenance.

One alternative strategy would be to develop a watershed-scale plan that prioritizes, for non-regulatory protection, specific geographic regions, or "hotspots," that support both highly productive vernal pools and high-quality upland forests. Funded by the Rhode Island Department of Environmental Management under an EPA Non-regulatory Wetland Pilot Demonstration Grant, we sought to create such a prioritization plan for the Queen's River watershed in southern Rhode Island, using knowledge and tools developed during our research over the past decade. We selected the Queen's River watershed because it falls within the larger Pawcatuck River watershed, where we have concentrated our work to date, and because several agencies and conservation organizations have identified this area as a conservation priority.

Methods

We conducted this research from January through December of 2006. We identified potential vernal pools from an aerial photographic inventory of pools produced by the Rhode

Island Chapter of The Nature Conservancy, our own inspection of more recent digital orthophotography, and fieldwork. We identified the owners of potential vernal pools from publicly available property records and attempted to contact each owner to secure permission for access. Of the 253 potential pools identified, we were able to access 135 (53%). After an initial visit to each site, we eliminated 33 pools because they were likely to support fish, which would render them less suitable for pool-breeding amphibians. During that first visit, we also mapped the perimeter of each pool using a GPS unit; later, we calculated pool size from the GPS data, using GIS software.

We returned to the 102 fishless pools one or more times to gather field data for estimating pool hydroperiod—the duration of flooding during most years—using one or both of two methods developed by project personnel between 2001 and 2005. The first method estimated pool hydroperiod from pool depth, canopy cover, and specific conductance of surface water—all determined in the field—as well as surficial geology and the combined area of upland and wetland forest within 1 km of the pool—determined from RIGIS. The second method estimated pool hydroperiod from the plants growing in the deepest zone. When neither method was applicable, or when the results of the two methods disagreed, we estimated pool hydroperiod based on our best professional judgment. We assigned each of the 102 fishless pools to one of four hydroperiod classes, based on a 1 March starting date: Class 1 (<20 wks), Class 2 (20-27 wks), Class 3 (28-36 wks), or Class 4 (>36 wks). Using GIS software and the RIGIS land use/land cover dataset, we also calculated the percent coverage of developed land, open land, water, wetland, and upland forest within 300 m and 1,000 m of each pool.

We ranked the potential contribution of each of the 102 fishless pools to pool-breeding amphibian productivity and diversity based on three key factors: pool size (ranked 1-3), pool hydroperiod (1-4), and the percent coverage of upland forest within 300 m of the pool (1-3). All of these habitat characteristics were correlated with egg-mass production by wood frogs and spotted salamanders in our earlier studies. Higher ranks reflected larger pools, longer hydroperiods, and greater forest cover. We summed the ranks for these three variables to achieve a rank for each pool. We did not rank the 33 pools believed to support fish. We did rank the 118 potential pools not visited, but solely on the basis of upland forest cover (1-3).

We identified amphibian hotspots, or geographic areas in the watershed that were potentially capable of supporting unusually high numbers or diversity of pool-breeding amphibians, as areas containing at least three high-ranking pools (final rank = 8-10 out of 10) within 1.5 km of each other. In delineating hotspots, we maximized the area of forest and minimized the area of developed land. We also identified forested corridors between hotspots that could be used by dispersing amphibians.

Results

Of the 102 fishless pools that we examined in the field, 31 were high-ranking (8-10), 52 were of intermediate rank (6-7), and 19 were low-ranking (4-5). We identified six hotspots ranging in size from 197 ha to 606 ha; together, they comprised 2,307 ha or 24% of the Queen's River watershed. Approximately 44% of the land within the hotspots is protected via acquisition in fee or conservation easements; watershed-wide, the figure is 24%. Combined, the six hotspots account for 96 (38%) of the 253 known or potential vernal pools in the watershed, including 27 (87%) of the high-ranking pools, 28 (54%) of the pools of intermediate rank, and 5 (26%) of the low-ranking pools. The three corridors that link the hotspots cover 1,110 ha, of which 41% is protected land. Upland forest is the most abundant land cover type in the corridors and in the hotspots. Developed land covers 5% or less of all corridors and all but one hotspot. We visited 64 of the 150 known or potential vernal pools that are located outside of the hotspots and corridors. Twenty-five of the 64 (39%) likely support fish. Of the 39 without fish, 14 (36%) were low-ranking, 22 (56%) were of intermediate rank, and 3 (8%) were high-ranking.

Discussion and Conclusions

The quality of pool-breeding amphibian habitat in the Queen's River watershed is relatively high, particularly compared to suburban and urban areas of Rhode Island. Of the 102 fishless pools that we were able to access, 81% ranked high or intermediate in terms of their potential ability to support a diverse, highly productive amphibian community. The six hotspots have especially high potential for meeting both aquatic and terrestrial habitat requirements of pool-breeding amphibians. Identification of hotspots and connecting corridors was straightforward once the pools were ranked and the ranks were displayed on a map that also showed upland forest cover and other land use/land cover types.

Overlaying amphibian hotspots, connecting corridors, and protected lands in the watershed clearly revealed the gaps—those valuable, but unprotected, areas that should be targeted for future land conservation. We believe that the first priority should be conservation of currently unprotected pools and surrounding upland forests within the six hotspots designated. Within a hotspot, pool ranks should be helpful in prioritizing conservation efforts at a finer scale.

Decisions to prioritize conservation efforts among hotspots might be based on the imminent threat of land development, the proportion of high-ranking pools present, or the extent of land not yet protected. Land conservation in the connecting corridors would provide high-quality terrestrial habitat that would allow migratory, pool-breeding amphibians to disperse among hotspots, thus enhancing long-term persistence of these species in the watershed. Natural or created vernal pools within these corridors also may serve as "stepping-stones" for animals repopulating regions where their numbers have declined.

Outside of the hotspots and corridors, protection of individual pools also may be prioritized using their ranks. In all cases, land acquisition in fee and perpetual conservation easements offer the best, long-term guarantee of habitat preservation. Where such vehicles are either not feasible or not justified, the quality of vernal pools and surrounding terrestrial habitats should be safeguarded through best management practices.

This prioritization scheme targets high-ranking pools and hotspots that contribute most to pool-breeding amphibian productivity and diversity at the watershed scale. There are some pools that might not be ranked highly by this method, or that might not be located within hotspots, but that still merit protection because of outstanding habitat value for rare or uncommon species; Class 1 pools supporting the Eastern spadefoot toad (*Scaphiopus h.*

holbrookii) are one example. Habitat conservation efforts for such species should be based on Rhode Island Natural Heritage Program data, which are managed by the Rhode Island Natural History Survey.

Several factors greatly enhanced our ability to accomplish this work expeditiously. Among them were (1) the availability of the TNC vernal pool inventory data for the Pawcatuck River watershed, of which the Queen's is a sub-basin; (2) the availability of wetlands, land use/land cover, and protected lands datasets from RIGIS; (3) the recent development of hydroperiod estimation methods by our own research team; and (4) the availability of project personnel with training in vernal pool ecology and GIS. We believe that the basic approach that we piloted in this study can be applied successfully in other watersheds, both in Rhode Island and elsewhere, but the efficiency and duration of such future projects will depend heavily on the availability of resources, tools, and personnel such as those listed above.

Attempting to reach landowners and to secure permission for access to potential vernal pools was one of the most time-consuming aspects of this project. Ultimately, we were able to visit roughly one-half of the potential vernal pools identified. Despite this seemingly low rate of cooperation, it is comparable to previous studies we have conducted, and we are confident that, in this case, a larger sample size would not have changed the number or location of hotspots markedly.

Collecting field data was essential to identifying pools supporting fish and for ranking fishless pools as habitat for pool-breeding amphibians. For this reason, and because of the time required to gain access to potential vernal pools, significant streamlining of this prioritization process in the future would be difficult to accomplish.

This report and database may be accessed via the DEM website at http://www.dem.ri.gov/programs/benviron/water/wetlands/index.htm.

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INTRODUCTION

Vernal pools serve as critical breeding, foraging, and resting habitat for a variety of vertebrates and invertebrates (Colburn 2004). In forested regions of New England, vernal pools tend to be small (<0.2 ha), shallow (<1 m), depressional wetlands that dry periodically. Some pools hold water from a few weeks to several months each year (defined by Cowardin et al. [1979] as temporarily flooded, seasonally flooded, or semipermanently flooded), while others dry once every few years (defined as intermittently exposed). Because they dry periodically, vernal pools do not sustain permanent fish populations, which could decimate amphibians and invertebrates that have limited defenses against predators (Semlitsch 1987, Kats et al. 1988).

Within Rhode Island, these non-permanent pools provide critical habitat for at least four amphibian species: wood frogs (*Rana sylvatica*), spotted salamanders (*Ambystoma maculatum*), marbled salamanders (*Ambystoma opacum*), and Eastern spadefoot toads (*Scaphiopus h. holbrookii*). Although dependent upon the pools for breeding and early development, most adult amphibians spend less than one month in pools each year (Paton and Crouch 2002). Following breeding, adults migrate to surrounding forests where they spend the remainder of the year; after metamorphosis, the young do the same (Colburn 2004). Once mature, the amphibians return to their natal vernal pool to mate and deposit eggs.

Recent research has shown that both landscape characteristics and features within the pool itself may influence the presence, abundance, and diversity of pool-breeding amphibians (Berven 1990, Rowe and Dunson 1995, Burne and Griffin 2005). Since 1997, we have identified many of the key characteristics contributing to the suitability and potential productivity of individual pools for wood frogs and spotted salamanders in Rhode Island (Egan and Paton 2004; Mitchell 2005; Montieth and Paton 2006; Egan and Paton, in press; Skidds et al. 2007). Among the most important within-pool factors affecting reproductive effort (number of egg masses) in these studies were the pool's size and hydroperiod, or duration of inundation. The amount of upland forest cover within various distances from a pool was the most important landscape factor associated with egg-mass counts. Although much of our research has been conducted in a single watershed—the Pawcatuck, ecological studies throughout the glaciated Northeast have reached similar conclusions (Homan et al. 2004, Hermann et al. 2005).

In recent years, protection of vernal pools has been a major conservation and regulatory goal throughout the United States. However, their small size, isolated nature, and seasonal drying make vernal pools difficult to identify and leave them increasingly at risk from human impacts (Gibbs 1993, Semlitsch and Bodie 1998). Historically, vernal pool protection has been largely a reactive process; wetland regulations have been applied when vernal pools could be identified and were threatened by land use changes. Additionally, wetland regulations, even if successful, may do little to maintain pool-breeding amphibian populations unless adjacent terrestrial habitat also is protected (Calhoun and Klemens 2002, Semlitsch and Bodie 2003, Gamble et al. 2006). One alternative strategy is to develop a watershed-scale plan that prioritizes for non-regulatory protection specific geographic regions that support both highly productive vernal pools and associated high-quality upland habitats. Identification of such amphibian "hotspots," based on the habitat requirements of key vernal pool indicator species such as wood frogs and spotted salamanders, would be of great assistance to public agencies and private organizations seeking to protect habitat through both regulatory and non-regulatory means.

Recently, we have generated the knowledge and tools to accomplish such habitat assessment and prioritization. During the last 5 years, we have developed two rapid-assessment methods to estimate a pool's long-term hydroperiod—one based on plants growing in the deepest zone of a pool (Mitchell 2005), and the other based on features such as basin depth, water chemistry, geology, and tree canopy cover (Skidds and Golet 2005). Development of these techniques is noteworthy because hydroperiod appears to be the single most important within-pool factor controlling productivity of pool-breeding amphibians, and these methods eliminate the need for prolonged monitoring of pools to determine hydroperiod. As noted above, we have also shown, through the use of GIS technology and land use/land cover data, that certain landscape characteristics, such as the amount of forest cover within 300-1,000 m of a pool, affect productivity.

This report describes how these tools were applied in a pilot project to prioritize non-regulatory conservation efforts directed toward pool-breeding amphibians. For this study, we focused on the Queen's River watershed because it falls within the larger Pawcatuck River watershed, an area we have studied for almost a decade, and both the Rhode Island Department of Environmental Management (RIDEM) and several nongovernmental conservation organizations have identified this relatively undeveloped area of Rhode Island as a conservation priority. The overall objective of this project was to identify specific hotspots, or geographic areas that are capable of supporting unusually high productivity or an unusually diverse community of pool-breeding amphibians as a basis for prioritizing land protection efforts. In the process of our research, we have assessed the efficacy of our hydroperiod estimation models and the practicality of identifying and ranking individual vernal pools and broader geographic areas on which to focus conservation efforts. Based on our findings, we offer suggestions for future watershed-based vernal pool protection efforts.

METHODS

Study Area

This project focused on the Usquepaugh-Queen's (henceforth, the Queen's) River watershed, which is located in the northeastern corner of the Pawcatuck River watershed in central southern Rhode Island; it is contained almost entirely within four towns: West Greenwich, Exeter, Richmond, and South Kingstown (Fig. 1). Lower order streams within this 9,488-ha watershed flow into the main stem of the Queen's River, which empties into Glen Rock Reservoir at the village of Usquepaugh and continues flowing south from there as the Usquepaugh River. The southern-most point of the watershed occurs at the junction of the Usquepaugh River and Chickasheen Brook, where water drains into the Pawcatuck River.

The landscape within the Queen's River watershed is relatively undeveloped, with almost 60% covered by upland forest (data from RIGIS; see August et al. 1995). Developed land (including residential, commercial, and industrial land); open land (including farms, brushland, and quarries); and wetlands cover 11%, 13%, and 15% of the landscape, respectively. More than 20% of the watershed is either under conservation easements or owned by organizations or agencies that work to maintain and protect natural systems, principally the Rhode Island Chapter of The Nature Conservancy (TNC), the Audubon Society of Rhode Island (ASRI), and RIDEM.

Vernal pool research that we conducted in the Pawcatuck River watershed between 2001 and 2005 produced two different hydroperiod estimation models, as well as detailed hydrologic, biologic, and geomorphic data on 65 vernal pools, 9 of which are found in the Queen's River watershed. Consequently, we were able to use those previously studied pools as reference sites and to be sure that our hydroperiod estimation models were applicable to this study.

Pool Identification

The pools in this study were identified in one of three ways: from conventional aerial photographs (contact prints), from digital aerial photography, or in the field. Of the 253 potential vernal pools identified in the Queen's River watershed for this project, 228 had been mapped earlier by TNC using 1995, 1:12,000-scale, panchromatic, aerial photographs. We

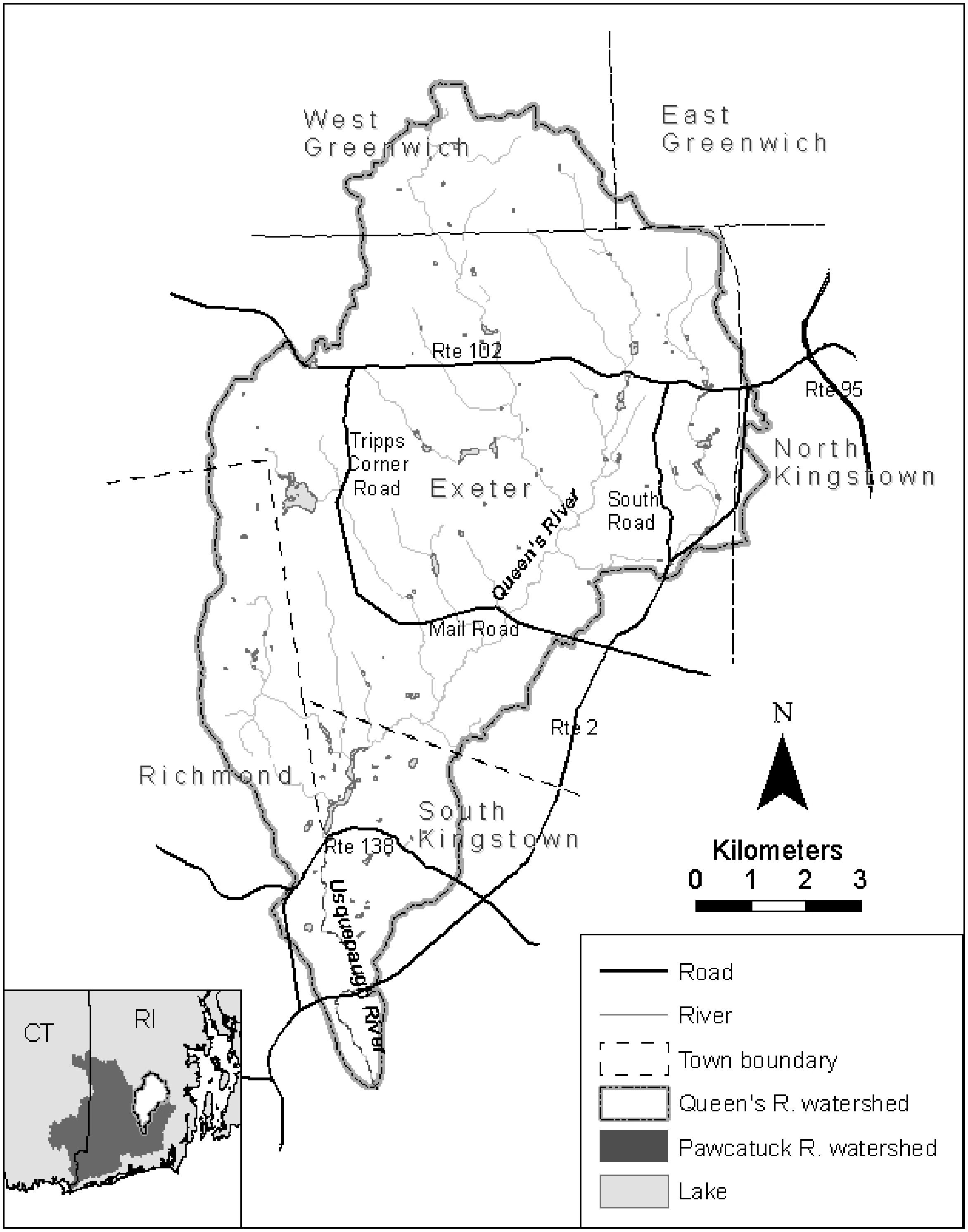


Figure 1. Geographic features of the Queen's River watershed in Rhode Island.

identified 14 more potential vernal pools using 2003/2004, 2-ft pixel, color, digital ortho-photography. During site visits to previously identified pools, we found, or were directed to, 11 additional pools.

Landowner Contacts

We identified landowners for potential vernal pools using publicly available property records. We felt that visiting as many pools as possible within the watershed was essential to complete an accurate assessment of amphibian habitat; therefore, we tried to contact landowners one or more times via letters, telephone calls, e-mails, and personal visits. Through our communications we briefly described the project, requested permission to access the property, and sought information relevant to our study (e.g., knowledge of pool drying or amphibians present). For examples of letters and more information on landowner contacts, see Appendix A.

Field Data Collection

Once landowner permission was granted, we visited each potential vernal pool at least once in 2006. During the initial visits, our primary goals were to locate the potential vernal pools, make contact with landowners, and identify pools that should be excluded from future visits, mainly due to the lack of suitable amphibian breeding habitat. Follow-up visits focused on data collection required by the two hydroperiod estimation models. During all visits, we recorded observations on within-pool and landscape characteristics that either were directly related to pool-breeding amphibians (e.g., presence of fish, amphibian egg masses, nature of surrounding habitat) or offered indirect indications of pool hydroperiod (e.g., rate of water level fluctuation, substrate composition, vegetation within the pool).

Initial site visits

Whenever possible, we spoke with landowners during our initial site visit to answer any questions or concerns they had about the project and to gain any knowledge they had of the pool (e.g., its creation, maintenance, hydroperiod, fish, or amphibians). We located pools in the field using printed copies of color, digital, aerial photographs; a compass; and a Garmin GPSmap76 that contained longitude and latitude positions of potential vernal pools. When practical (i.e., not in dense underbrush), we used a differential beacon receiver and antenna to improve upon GPS positional accuracy; however, under a forest canopy, the beacon receiver and antenna offered little advantage over the GPS unit alone.

During our initial field visits, we also recorded information concerning breeding and upland habitat for pool-breeding amphibians. At every pool, we recorded observations on several within-pool characteristics, including current depth and normal high-water depth; relative canopy cover; inlets or outlets; presence or absence of vegetation; prevalence of attachment sites for amphibian egg masses; indicators of human impacts or disturbance (e.g., dumping, excavating, berms, trenches, culverts); and indicators of aquatic wildlife including amphibians, fish, and beavers. The presence of beavers was used as an indicator of the permanence of contiguous waters and, possibly, of the pool itself. We also recorded field notes on surrounding landscape composition, including the proximity of other water bodies and wetlands; the land cover (e.g., field, road, deciduous forest, yard) immediately adjacent to the pool and more than 100 m from the pool; and the current condition of that land cover (e.g., recently abandoned field, mature forest, seldom-traveled dirt road).

Observations from this initial visit enabled us to exclude pools if we felt they would not serve as suitable breeding habitat for wood frogs or spotted salamanders. Generally, pools were excluded based upon the presence, or likely presence, of fish. We assumed a pool would regularly support a fish population if (1) landowners reported stocking the pool with fish; (2) landowners reported, and field observations supported, the presence of fish; (3) we observed fish in the pool; or (4) landowners reported, or our field observations supported, the pool having a permanent or semi-permanent water regime and a likely source of fish, such as inlets and outlets leading to permanent water bodies. We assumed that a pool was permanent or semi-permanent if it was greater than 2 m deep, had an organic substrate, or lacked emergent vegetation in deeper areas of a sunlit pool. Although certain pools may not have sustained breeding populations of fish on their own, they were considered capable of supporting fish if they were hydrologically linked—even intermittently—to permanent water bodies. All such sites were excluded from return visits. We have rarely observed wood frog or spotted salamander egg masses in such pools, and never in large quantities. On the other hand, potentially permanent pools located at the headwaters of first-order streams were not excluded from further study. We assumed that fish could not access such up-gradient pools. This assumption was supported by the large numbers of wood frog and spotted salamander egg masses often observed in these headwater pools and by the lack of observations of fish there.

Using the GPS unit, we mapped the perimeter of each pool at the ordinary high-water level. Features used as indicators of the ordinary high-water level included: the poolward limit of upland vegetation; outlet elevations; lichen and moss growth on trees; and, during spring months, the pool shoreline. When located within a wetland complex, vernal pool boundaries were placed at the edge of an identifiable basin or at the transition to flowing water (i.e., at the start of an intermittent inlet or outlet), if present. In a few instances, pools were adjacent to a forested wetland and the abrupt change in vegetation was useful in delineating the pool. We also used notes and sketches to describe the shape and extent of pools. Prior to the first visit, we heads-up digitized pool perimeters in ArcMap (ESRI 2004) using 2003/2004, leaf-off, color orthophotographs. We then used the GPS points, sketches, and field notes to correct the GIS polygons representing pool perimeters. A comparison of the pool perimeters digitized prior to the field visit with the perimeters delineated following the GPS work and field corrections showed marked differences in the shape and extent of many pools; for this reason, only pools that we visited had a delineated polygon and size associated with them.

Follow-up visits

As noted above, during previous research we developed two different methods to estimate a vernal pool's usual hydroperiod from data gathered during a single field season. During that work, we defined pool hydroperiod as the number of weeks a pool holds water from 1 March until it first dries (see "Estimating Pool Hydroperiod Class" below). Because of annual variation, we described a pool's hydroperiod as the maximum hydroperiod the pool achieves in most years (i.e., >50% of years). We recognized four hydroperiod classes: Class 1, hydroperiod <20 weeks in most years; Class 2, hydroperiod 20-27 weeks in most years; Class 3, hydroperiod 28-36 weeks in most years; and Class 4, hydroperiod >36 weeks in most years (Mitchell 2005).

We returned to pools identified as not supporting fish populations to collect data for estimating pool hydroperiod class. We established three transects in each pool; the primary transect was located along the longest axis of the pool and two secondary transects were perpendicular to the primary transect at one-third and two-thirds of the way along its length. Transects began and ended at the ordinary high-water mark of a pool. We determined canopy cover from observations of the presence or absence of woody plants overhead at 1-m intervals along each of three transects using a densitometer.

We calculated open basin depth, a strong predictor of mean hydroperiod (Skidds and Golet 2005), as the difference between the mean elevation of the soil at the base of six red maple (*Acer rubrum*) trees growing closest to the pool and the deepest point in the pool. Elevation was measured using a Topcon AT-G6 auto-level and rod. A few pools did not have six red maples at which to measure elevation; at these pools we measured ground elevation at as many red maples as possible.

We identified the surficial geologic types of pool basins by overlaying in GIS the complete vernal pool dataset and a soil parent material layer created by Rosenblatt (2000) from the Rhode Island Soil Survey (Rector 1981). Categories included alluvium, glacial fluvial material, loose till, and dense till. We checked geologic type with a soil auger.

We measured specific conductance of surface water in the field using an Oakton pH/CON 10 meter at three randomly selected locations within each pool during late July. Measurements were taken at least 2 m from the pool's edge and at least 30 cm below the surface whenever possible; we took measurements in the middle of the water column in pools less than 40 cm deep. We were unable to measure specific conductance at five sites that dried before mid-July.

We recorded all plant species observed in each pool and noted which species occurred in the deepest zone, defined as that area within a 1.5-m radius of the deepest point in the pool. Besides collecting data to estimate hydroperiod, we also noted other indications of hydroperiod or potential pool drying. For example, we recorded observations of short-term changes in water level within a pool, amphibian presence (both larval and adult), and the depth of organic soil material.

Landscape Characterization

We gathered data on the landscape surrounding individual pools using GIS technology. All analyses were done using ESRI software, Arc 9.0 and ArcMap 9.0 (ESRI 2004), and GIS data layers available online from RIGIS (http://www.edc.uri.edu/rigis-spf/RIGIS.html), except for the potential vernal pool data layer, which was obtained from TNC and supplemented by our field observations. We calculated the percent coverage of various land use and land cover types within 300 m and 1,000 m of each pool based on 1995 data from RIGIS. To simplify the description of land use and land cover, and to create categories relevant to pool-breeding amphibians, we grouped the 37 RIGIS classifications into five broad types: developed land, open land, water, wetland, and upland forest. Land identified as developed included all residential, industrial, and commercial development, transportation systems, and cemeteries. Power lines and vacant land, although grouped with other developed land in RIGIS, were considered open land. Additionally, we categorized all land uses coded within the 200-, 400-, and 700-levels, such as agricultural land, rock outcrops, transitional barren areas, and brushland, as open land. Upland forest included deciduous, evergreen, and mixed forests, all coded within the 300-level. Water included all areas of open water, including lakes, ponds, and wide river channels. Wetland areas were identified based on the RIGIS wetlands data layer and included emergent, shrub, and forested wetlands. For the purposes of estimating pool hydroperiod class using the Skidds model (see below), we calculated total forest cover within 1,000 m of a pool by combining the percentage of wetland forest from the RIGIS wetlands data layer with the percentage of upland forest from the land use/land cover data layer.

Estimating Pool Hydroperiod Class

The two hydroperiod estimation methods that we used were the Skidds model, modified from Skidds and Golet (2005), and the plant method, developed by Mitchell (2005). The Skidds model relied on one landscape variable (total forest cover within 1,000 m of the pool) and four within-pool variables (percent canopy cover, open basin depth, specific conductance, and surficial geology) to estimate pool hydroperiod; the resulting value in weeks was then translated into one of the four hydroperiod classes described above (see "Follow-up visits"). The plant method required the identification of plant species within the deepest zone of a pool to estimate pool hydroperiod class (Mitchell 2005). We were unable to apply the plant method at pools lacking vegetation in the deepest zone and could not use the Skidds model at pools that dried before we could sample specific conductance.

We estimated hydroperiod class for every pool visited using the Skidds model, the plant method, both methods, or, when field data were not available to apply either method, our best professional judgment. If the hydroperiod class estimates from the Skidds model and the plant method agreed, then that class was considered to be the final estimate. When the estimates disagreed, we usually based the final hydroperiod class estimate on the plant method.

Using the Skidds model, pool hydroperiod (in weeks, based on a 1 March start date) was calculated as follows:

$$45.34 - 5.6\times10^{-2}(\text{forest}) - 15.79(\text{canopy}) + 3.99(\text{depth}) - 4.22(\text{alluvial}) + 6.75\times10^{-2}(\text{conductance})$$

where *forest* is the area of land in hectares within 1,000 m of a pool that was covered by either upland forest or wetland forest, *canopy* is the percent overhead canopy cover as determined along the three transects, *depth* is open basin depth in meters, *alluvial* is an ordinal variable (with alluvial sites assigned a 1 and non-alluvial sites assigned a 0), and *conductance* is the average of three specific conductance measurements in microSiemens within a pool.

Using the plant method, we estimated the hydroperiod class of pools based upon the mean hydroperiod class of all plant species present in the deepest zone. Hydroperiod class values determined for many common wetland plants by Mitchell (2005) appear in Table 1. If no plants were present in the deepest zone, we estimated a hydroperiod class based upon the plants growing closest to the deepest zone; however, that estimate was used only as a minimum value when assigning a hydroperiod class to the pool. Plants growing within a mat

Table 1. Hydroperiod class of vernal pool plants as determined by Mitchell (2005).

Scientific name[a]	Common name	Plant hydroperiod class
Acer rubrum	Red maple	1
Athyrium filix-femina	Northern lady fern	1
Betula alleghaniensis	Yellow birch	1
Betula lenta	Sweet birch	1
Betula populifolia	Gray birch	1
Carex bullata	Button sedge	2
Carex lasiocarpa	Hairy-fruited sedge	2
Carex oligosperma	Few-seeded hop sedge	3
Carex stricta	Tussock sedge	1
Chamaecyparis thyoides	Atlantic white cedar	1
Decodon verticillatus	Swamp loosestrife	3
Dulichium arundinaceum	Three-way sedge	2
Eleocharis acicularis	Least spike rush	2
Eleocharis palustris	Marsh spike rush	3
Fraxinus spp.	Ash	2
Galium tinctorium	3-lobed bedstraw	2
Glyceria acutiflora	Mannagrass	1
Glyceria canadensis	Rattlesnake mannagrass	3
Glyceria obtusa	Atlantic mannagrass	2
Glyceria septentrionalis	Floating mannagrass	3
Hypericum boreale	Marsh St. John's wort	2
Impatiens capensis	Jewelweed	1
Iris versicolor	Northern blue flag	2
Juncus canadensis	Marsh rush	2
Juncus effusus	Soft rush	1
Lycopus virginicus	Virginia water-horehound	1
Lysimachia terrestris	Swamp candle	2

Table 1. (Concluded).

Scientific name[a]	Common name	Plant hydroperiod class
Nuphar variegata	Yellow water lily	4
Nymphaea odorata	White water lily	3
Nyssa sylvatica	Black gum	1
Onoclea sensibilis	Sensitive fern	2
Osmunda cinnamomea	Cinnamon fern	1
Osmunda regalis	Royal fern	2
Potamogeton natans	Floating pondweed	4
Proserpinaca palustris	Common mermaid weed	2
Puccinellia pallida	Pale mannagrass	2
Quercus bicolor	Swamp white oak	1
Quercus palustris	Pin oak	1
Rhexia virginica	Wing-stem meadow-beauty	2
Rubus hispidus	Swamp dewberry	1
Sagittaria latifolia	Common arrowhead	2
Sassafras albidum	Sassafras	1
Scirpus cyperinus	Woolgrass	2
Sparganium americanum	Common bur-reed	2
Sphagnum spp.	Sphagnum moss	2
Symplocarpus foetidus	Skunk cabbage	1
Thelypteris palustris	Marsh fern	1
Triadenum virginicum	Northern St. John's wort	2
Typha latifolia	Broad-leaved cattail	2
Utricularia spp.	Bladderwort	3
Vaccinium macrocarpon	Large cranberry	2
Viola lanceolata	Strap-leaved violet	1
Viola primulifolia	Primrose-leaved violet	1
Woodwardia virginica	Virginia chain-fern	2

[a] Follows Gleason and Cronquist (1991).

of floating vegetation not attached to the pool bottom were not used to estimate hydroperiod class.

Because the hydroperiod class estimates for an individual pool frequently did not agree, the final class assignment was made after considering several other hydroperiod indicators; these factors provided the basis for our "best professional judgment" estimate. The degree of fluctuation of the water level within a potential vernal pool, coupled with information on maximum pool depth and 2006 precipitation levels, offered some indication of whether the pool was likely to dry. Generally, pools whose levels do not fluctuate much during the year are less likely to dry. Because both green frogs (*Rana clamitans melanota*) and American bullfrogs (*Rana catesbeiana*) require more than one year of larval development, the presence of green frog or bullfrog larvae during spring and early summer months generally indicated that a pool did not dry during the previous year. Another useful characteristic was the depth of organic soil material, or muck. Based on our experience, pools with >30 cm (approximately) of muck at the deepest point have longer hydroperiods (Class 3 or 4) simply because organic matter decomposition is very slow in soil with prolonged inundation.

Ranking Individual Pools

After a review of relevant literature and conducting correlation analyses on data from 65 pools that we had studied within the Pawcatuck River watershed between 2001 and 2004, we identified those habitat variables that were most strongly related to spotted salamander and wood frog egg-mass production. Those analyses also enabled us to eliminate certain independent variables that were strongly correlated with each other, thereby reducing redundant factors and simplifying the ranking. We ranked each pool based on three key habitat factors: (1) the pool's size, (2) the pool's hydroperiod class, and (3) percent upland forest within 300 m of the pool.

The hydroperiod classes that we used were developed by Mitchell (2005) and reflect differences in maximum egg-mass counts of wood frogs and spotted salamanders over a 4-year period. For both species, breeding effort increased from Class 1 to Class 3, then declined in Class 4 to approximately the Class 2 level. Thus, hydroperiod class can be used as a predictor of potential productivity for these species. Additionally, work by Paton and Crouch (2002) suggests that these hydroperiod classes may be useful for assessing habitat suitability for several other pool-breeding amphibians as well.

We assigned each pool a rank of 1, 2, or 3 for both pool size and surrounding upland forest cover and a rank of 1, 2, 3, or 4 for hydroperiod, with higher ranks indicating better habitat (Table 2). Pools with an upland forest cover rank of 1 had <30% cover within 300 m of the pool; a rank of 2 indicated 30%-60% cover within 300 m, and a rank of 3 indicated >60% cover. We ranked pool size as follows: rank of 1 for pools <0.05 ha; rank of 2 for pools 0.05-0.15 ha; and rank of 3 for pools >0.15 ha. Hydroperiod class ranks were as follows: Class 1 had a rank of 1, Class 2 had a rank of 2, Class 3 was assigned a rank of 4, and Class 4 was assigned a rank of 3. We assigned Class 3 the highest rank because vernal pool amphibian productivity tends to be greatest in Class 3 pools (Mitchell 2005).

Because the ranking of individual pools required field data, we first classified pools as (1) not visited; (2) visited, but with fish definitely or very likely present; or (3) visited, with fish definitely or very likely absent (Table 2). The final rank for visited pools without fish was based on the sum of ranks for all three variables—pool hydroperiod class, pool size, and surrounding upland forest cover—with a possible range from 3 to 10 (Table 2). For discussion purposes, we grouped pools into categories based upon their rank; pools ranked 8-10 were considered high-ranking, pools ranked 6 or 7 were considered intermediate in rank, and pools ranked 3-5 were considered low-ranking, relative to other pools in this study. Pools that we did not visit were ranked solely on the basis of surrounding upland forest cover—information that did not require a field visit; ranks ranged from 1 to 3 (Table 2).

Visited pools known, or likely, to support fish were not ranked because studies indicate that they would offer little value as habitat for spotted salamanders or wood frogs (Kats et al. 1988, Hecnar and M'Closkey 1996). It should be noted, however, that we have observed both wood frog and spotted salamander egg masses in permanent pools that support fish (Egan and Paton 2004, Mitchell 2005). Although these pools are not likely to be highly

Table 2. Methodology for classifying and ranking individual vernal pools.

Site visit?	Presence of fish?	Pool variables	Classes	Class ranks	Final pool rank
Site visited	Fish population present or likely	Not considered	NA	NA	Not ranked
	Fish population absent or unlikely	Pool hydroperiod class	Class 1	1	Sum of three class ranks, one rank per variable Ranges from 3 to 10
			Class 2	2	
			Class 3	4	
			Class 4	3	
		Pool area (hectares)	< 0.05	1	
			0.05 - 0.15	2	
			> 0.15	3	
		Upland forest within 300 meters (percent)	< 30	1	
			30 - 60	2	
			> 60	3	
Site not visited	Fish population unknown	Upland forest within 300 meters (percent)	< 30	1	Ranges from 1 to 3
			30 - 60	2	
			> 60	3	

productive for these amphibian species, permanent pools with fish may be useful as "stepping-stones" for the dispersal of vernal pool species and as breeding habitat during drought years, when other pools dry too early for successful reproduction.

Identifying Amphibian Hotspots and Corridors

We identified specific geographic areas within the Queen's River watershed that are potentially capable of supporting unusually high productivity or high diversity of pool-breeding amphibians based on the location of high-ranking vernal pools (rank = 8-10) and the landscape surrounding those pools. To identify hotspots, we looked for pool clusters containing at least three high-ranking pools. Pools within 1.5 km of each other were usually grouped together, including pools that had not been visited. Because of the value forested landscapes provide to most pool-breeding amphibians, we maximized the area of forested land and minimized the area of developed land during delineation of each hotspot. We extended hotspot boundaries at least 300 m beyond pools that were near the edges of hotspots as long as the surrounding habitat was not a developed land use.

We also identified landscape corridors connecting hotspots, where possible. Corridors were identified as areas with contiguous forest cover that might contain vernal pools that could serve as "stepping-stones" between hotspots for dispersing juvenile amphibians. We delineated corridors that connected at least two hotspots.

RESULTS

Pool Hydroperiods, Size, and Forest Cover

Of the 253 potential vernal pools identified in this study, we did not receive permission to access 118, all of which were on private property and 9 of which were held in conservation easements by RIDEM. We visited 135 pools on land owned by private citizens, nongovernmental conservation organizations, municipalities, or state agencies. Thirty-three (25%) of those pools supported, or were likely to support, fish populations, so we did not collect detailed field data at those sites. We estimated the hydroperiod class of the remaining 102 vernal pools. Based on our final hydroperiod estimates, 17 fishless pools were in Class 1, 51 were in Class 2, 19 were in Class 3, and 15 were in Class 4 (Fig. 2). All 33 pools that we identified as supporting, or likely supporting, fish populations were assumed to be in Class 4.

Pool size for the 102 fishless vernal pools ranged from <0.01 ha (3 pools) to >1.0 ha (4 pools), with none larger than 1.5 ha; 73% were 0.2 ha or smaller (Fig. 3). Of the 11 pools newly identified in the field, 9 were < 0.10 ha. Although pools with fish occurred throughout the same size range as pools without fish, 6 of the 10 largest pools (>1.0 ha) supported fish populations.

Percent upland forest cover within 300 m of a pool was normally distributed (Fig. 4); both the mean and median cover values were 49%. Based on an analysis of the 1995 land use/land cover data from RIGIS, upland forest covers 59% of the Queen’s River watershed, 57% of the Pawcatuck River watershed, and 43% of Rhode Island.

Agreement Between Skidds and Plant Methods

We estimated the hydroperiod class of 102 vernal pools. We applied the Skidds model at 56 pools, used the plant method at 60 pools, and used our best professional judgment alone at 24 pools because field data required for the Skidds model and the plant method were lacking. We used both the Skidds model and the plant method to estimate hydroperiod at 38 pools. In 15 of those cases (39%), the estimates agreed. Hydroperiod estimates based on the Skidds model—either alone or in conjunction with the plant method—agreed with the final

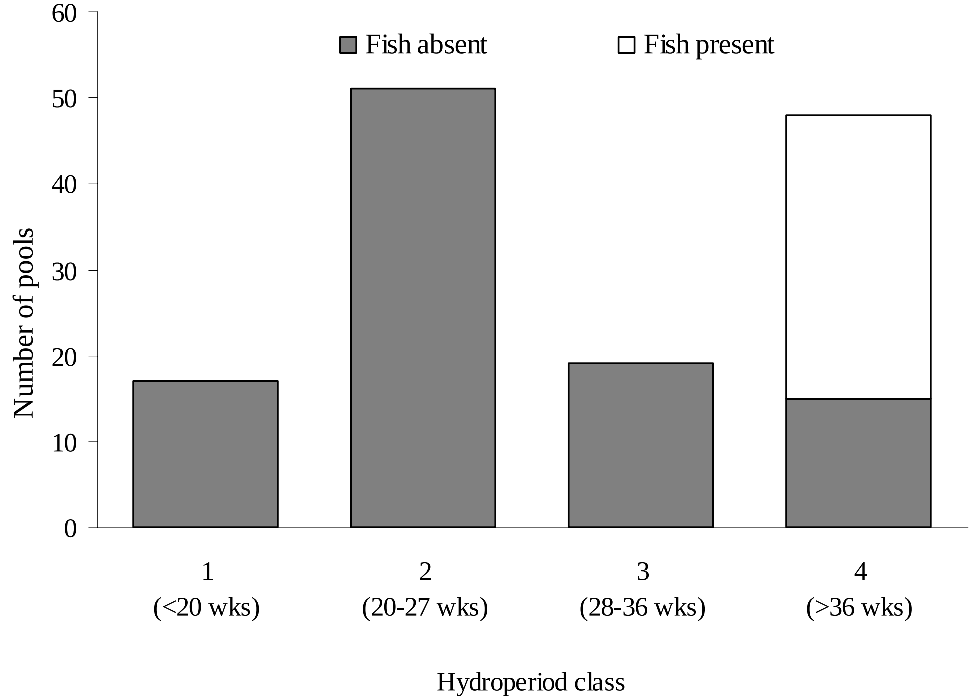


Figure 2. Distribution of 135 visited pools among four hydroperiod classes. Thirty-three pools support, or likely support, a fish population. Hydroperiod classes are based on a 1 March starting date.

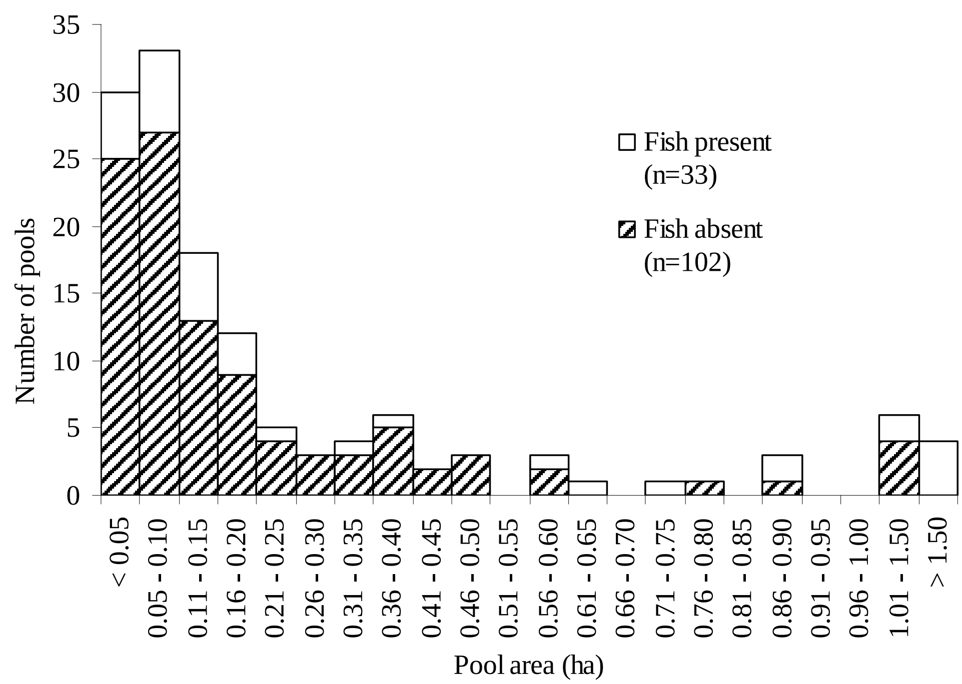


Figure 3. Distribution of visited pools, with and without fish, by size.

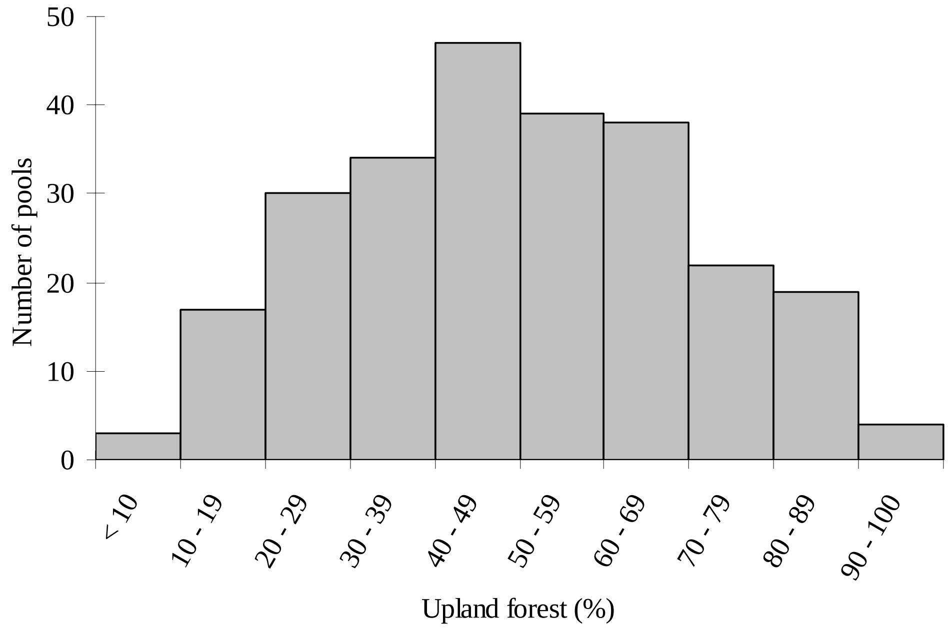


Figure 4. Distribution of upland forest cover within 300 m of potential and confirmed vernal pools.

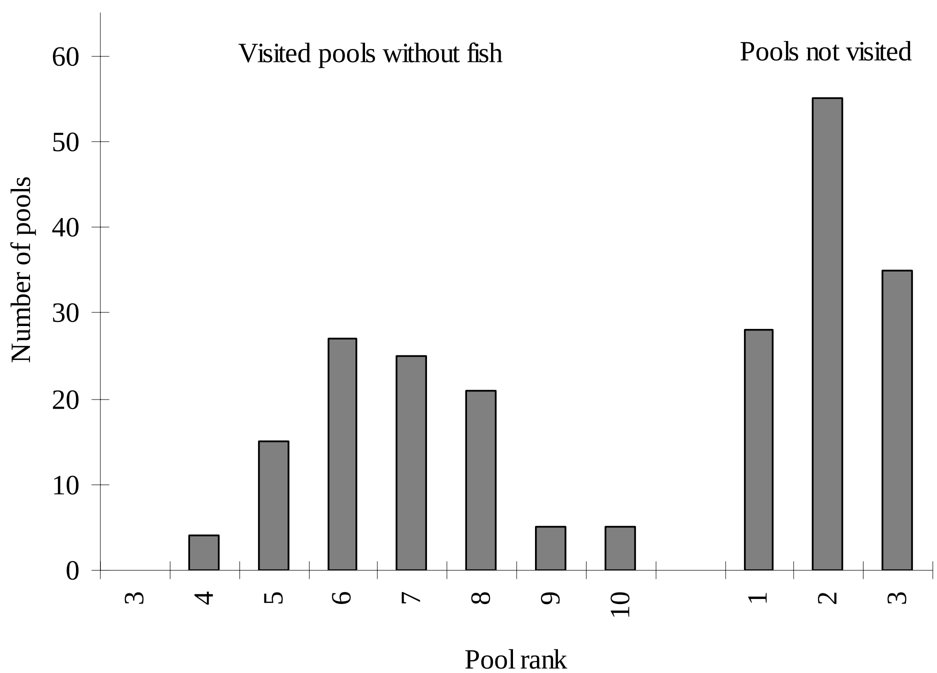


Figure 5. Distribution of visited pools without fish, and pools not visited, by pool rank.

hydroperiod estimate in 45% of the cases, whereas estimates based on the plant method agreed with the final estimate 87% of the time.

Pool Ranks

For the 102 pools we visited that did not support fish, ranks were normally distributed; the lowest rank was 4 (4 pools) and the highest rank was 10 (5 pools) (Fig. 5). No fishless pools received the lowest possible rank of 3. Thirty-one pools were classified as high-ranking (8, 9, or 10), 52 pools had an intermediate rank (6 or 7), and 19 pools were low-ranking (4 or 5). Based on an assessment of adjacent upland forest cover only, a rank of 2 (30-60% cover) was most common for pools not visited (Fig. 5).

Amphibian Hotspots

We identified six amphibian hotspots, or geographic areas that are likely to be very productive for pool-breeding amphibians (Fig. 6). Identified by the letters A-F from northwest to southeast, they range in size from 197 ha to 606 ha and together comprise 2,307 ha (24%) of the 9,488-ha Queen's River watershed (Table 3). Approximately 44% of the land within the hotspots is currently protected; over the entire watershed, the figure is 24% (Table 3, Fig. 7). Upland forest cover for four of the hotspots is at least 70%, while upland forest and wetland together comprise at least 85% of every hotspot (Fig. 8). Five of the six hotspots contain 5% or less developed land (Table 3). Combined, the six hotspots account for 96 (38%) of the 253 known or potential vernal pools identified in this study (Table 3). Included within the hotspots are 27 (87%) of the 31 high-ranking pools, 28 (54%) of the 52 pools of intermediate rank, and 5 (26%) of the 19 low-ranking pools. The hotspots also include 7 pools with fish and 29 pools that were not visited. Below is a brief description of each.

Hotspot A. - Located north of Route 102 (Ten Rod Road) within the towns of West Greenwich and Exeter, in the northwestern corner of the Queen's River watershed (Fig. 6). This hotspot covers 416 ha, of which 81% is upland forest (Table 3, Fig. 8). It contains 12 vernal pools, 6 of which are high-ranking, 3 of intermediate rank, and 1 low-ranking; 2 were not visited during this study. Pool density is 2.9/sq km. More than 200 ha (49%) of the

Figure 6. (Next page) Locations of vernal pools, amphibian hotspots, and connecting corridors within the Queen's River watershed. Ranked pools are identified either as triangles, indicating that they were not visited and were ranked by upland forest cover within 300 m only; or as circles, indicating that they were visited and were ranked by pool size, hydroperiod, and upland forest cover. Squares represent pools that likely support fish and were not ranked. If pools are very close together, symbols may overlap.

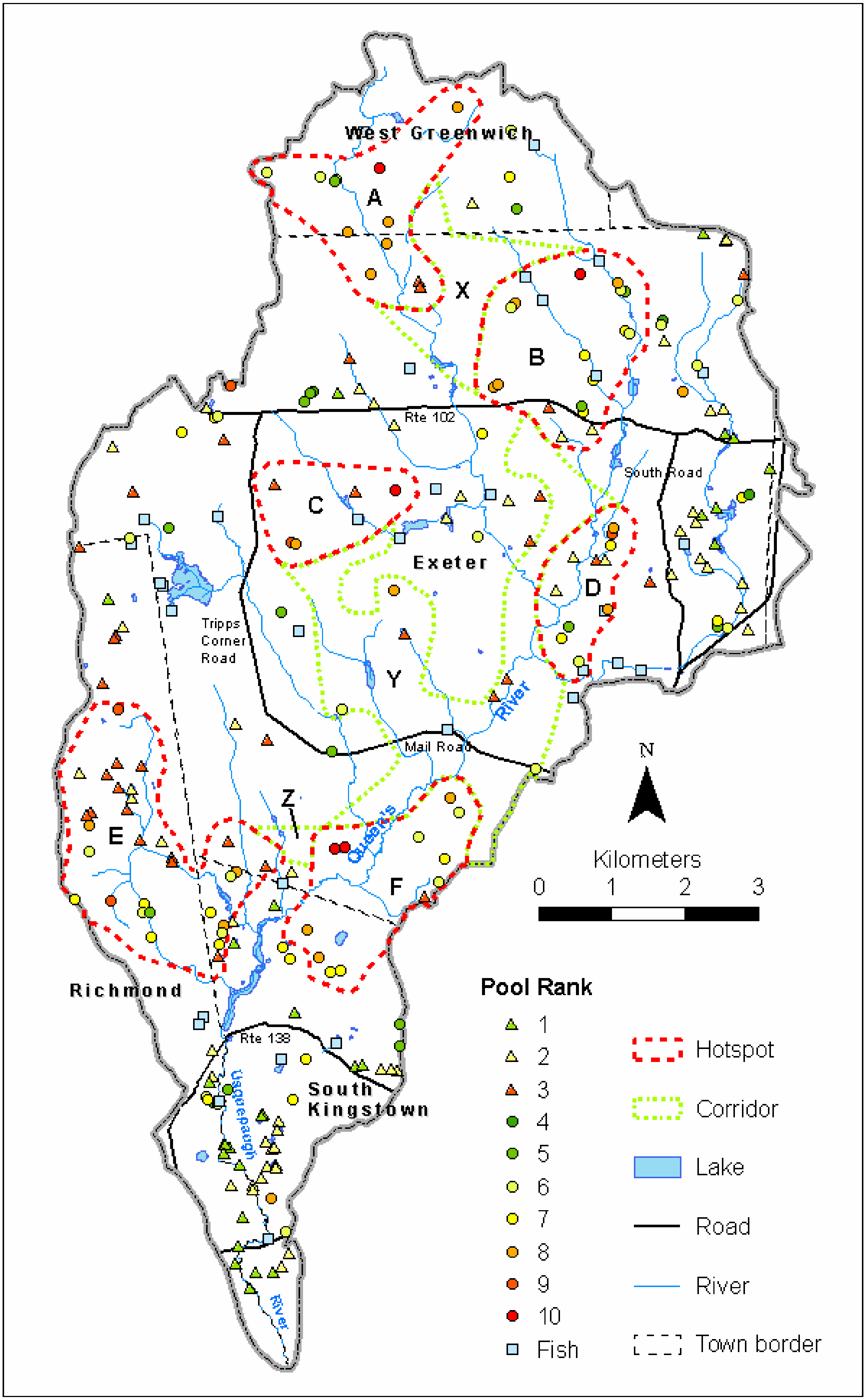

West Greenwich
A
X
B
Rte 102
C
South Road
Exeter
D
Tripps Corner Road
Y
River
Mail Road
Z
E
Queen's
F
Richmond
Rte 138
South Kingstown
Usquepaugh
River
N
Kilometers
0 1 2 3
Pool Rank
1
2
3
4
5
6
7
8
9
10
Fish
Hotspot
Corridor
Lake
Road
River
Town border

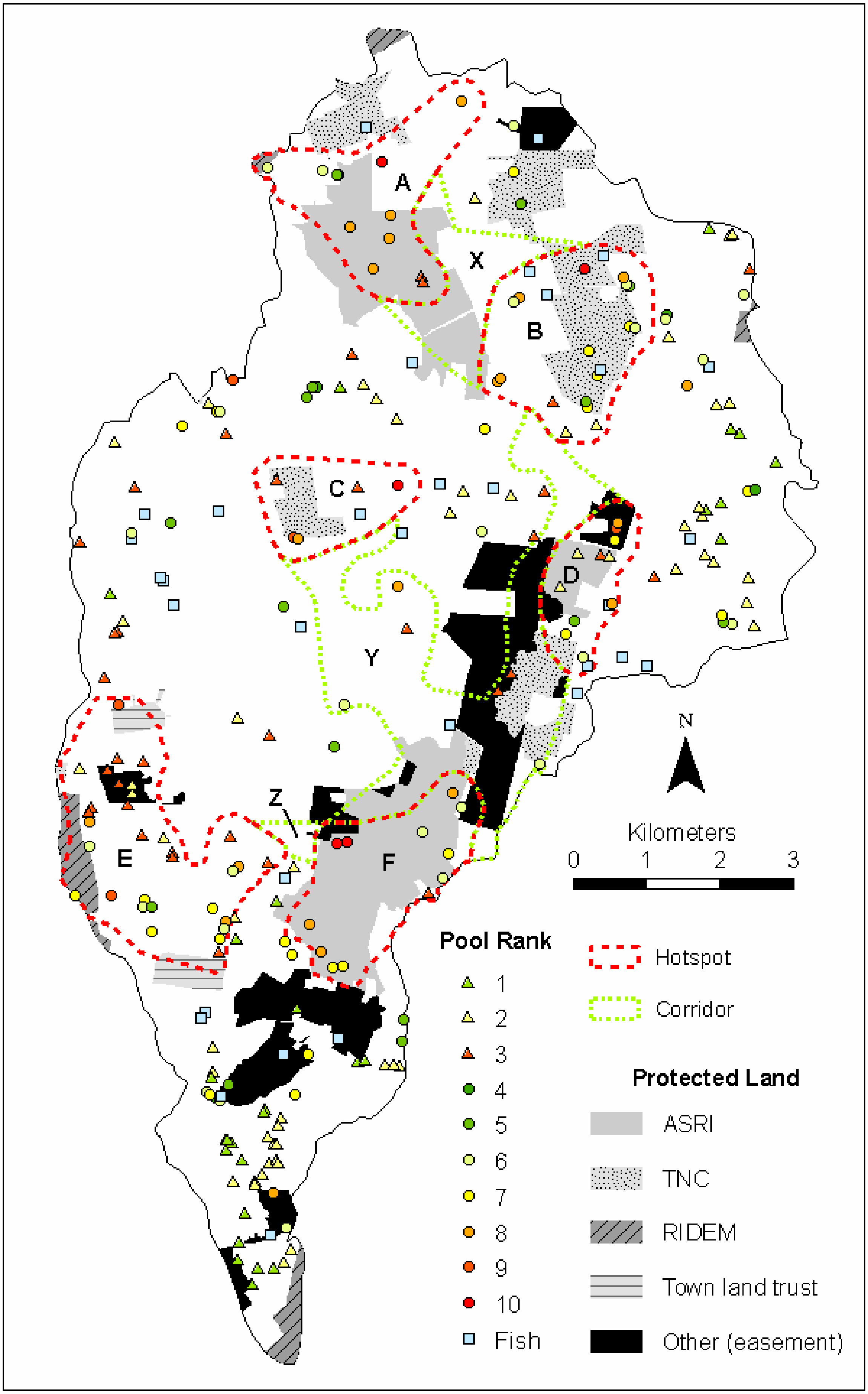
Table 3. Land cover, land protection status, and number and rank of vernal pools within hotspots, corridors, and the Queen's River watershed as a whole.

		Hotspot						
Land cover		A	B	C	D	E	F	Total
Developed	ha	16	21	11	4	59	4	115
	(%)	*(4)*	*(5)*	*(5)*	*(2)*	*(10)*	*(1)*	*(5)*
Upland forest	ha	339	345	187	85	426	228	1,610
	(%)	*(81)*	*(74)*	*(83)*	*(43)*	*(70)*	*(57)*	*(70)*
Water	ha	<1	<1	1	1	2	5	9
	(%)	*(<1)*	*(<1)*	*(<1)*	*(<1)*	*(<1)*	*(1)*	*(<1)*
Wetland	ha	42	87	25	82	91	146	473
	(%)	*(10)*	*(19)*	*(11)*	*(42)*	*(15)*	*(37)*	*(21)*
Open land	ha	19	11	2	25	28	15	100
	(%)	*(5)*	*(2)*	*(1)*	*(13)*	*(5)*	*(4)*	*(4)*
Total	ha	416	464	226	197	606	398	2,307
Protected land	ha	203	195	58	112	105	348	1,021
	(%)	*(49)*	*(42)*	*(26)*	*(57)*	*(17)*	*(87)*	*(44)*
Number of pools								
Pools not visited		2	3	2	4	17	1	29
Pools visited		10	18	4	9	15	11	67
Total		12	21	6	13	32	12	96
Pools by rank								
Pools with fish		0	4	1	2	0	0	7
	1	0	0	0	0	0	0	0
Not visited	2	0	2	0	3	4	0	9
	3	2	1	2	1	13	1	20
	4	0	0	0	0	0	0	0
	5	1	2	0	1	1	0	5
	6	3	3	0	1	4	3	14
Visited	7	0	4	0	2	5	3	14
	8	5	4	1	2	3	3	18
	9	0	0	1	1	2	0	4
	10	1	1	1	0	0	2	5
Total		12	21	6	13	32	12	96

Table 3. (Concluded).

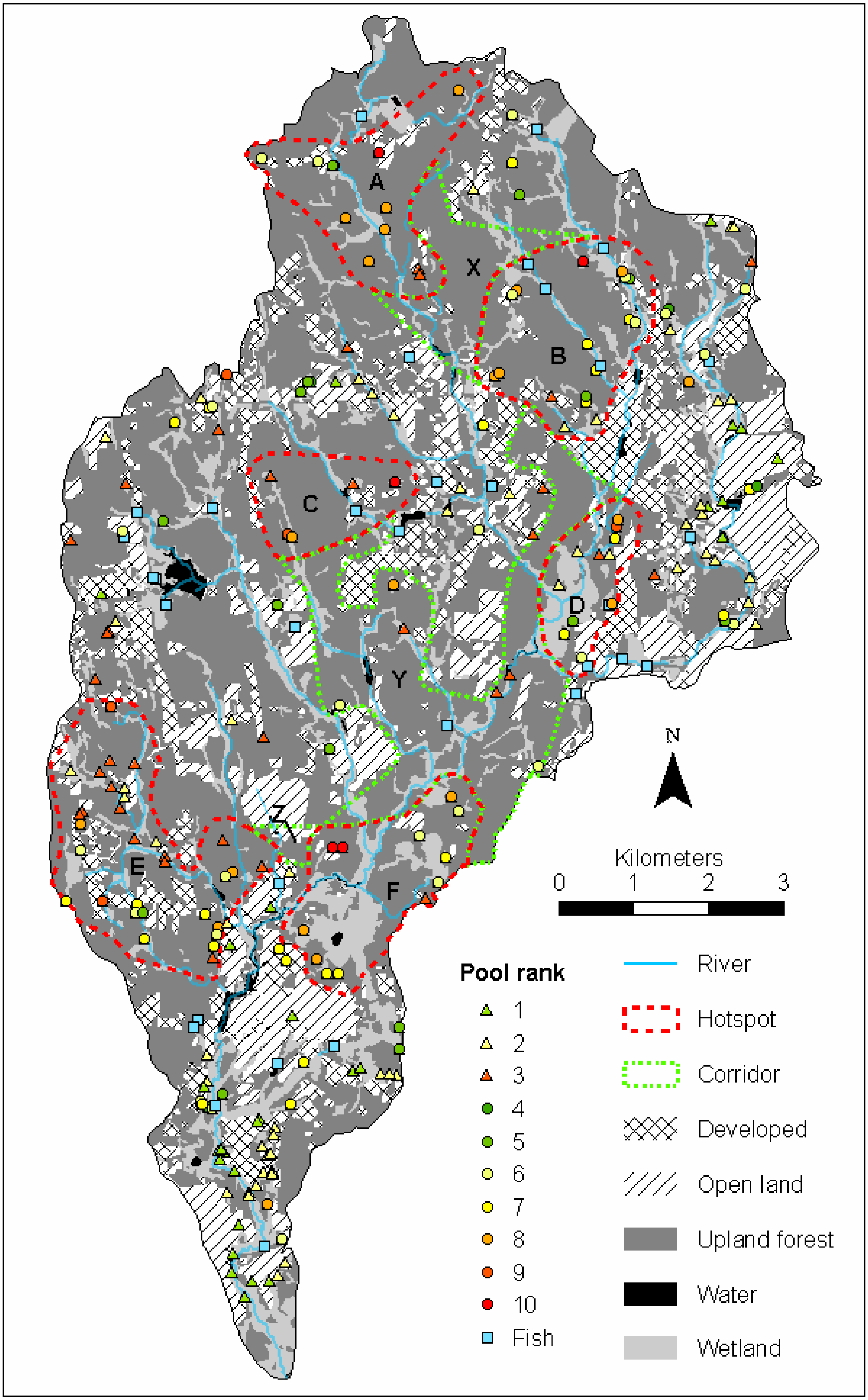
Land cover		X	Y	Z	Corridor Total	Not corridor/ hotspot	Queen's River Watershed
Developed	ha	1	22	1	24	954	1,093
	(%)	*(<1)*	*(3)*	*(4)*	*(2)*	*(16)*	*(12)*
Upland forest	ha	192	681	16	889	3,106	5,605
	(%)	*(84)*	*(79)*	*(62)*	*(80)*	*(51)*	*(59)*
Water	ha	2	5	<1	7	62	78
	(%)	*(<1)*	*(<1)*	*(<1)*	*(<1)*	*(1)*	*(1)*
Wetland	ha	27	126	1	154	828	1,455
	(%)	*(12)*	*(15)*	*(4)*	*(14)*	*(14)*	*(15)*
Open land	ha	6	22	8	36	1,121	1,257
	(%)	*(3)*	*(3)*	*(31)*	*(3)*	*(18)*	*(13)*
Total	ha	228	856	26	1,110	6,071	9,488
Protected land	ha	109	343	1	452	803	2,276
	(%)	*(48)*	*(40)*	*(4)*	*(41)*	*(13)*	*(24)*
Number of pools							
Pools not visited		0	3	0	3	86	118
Pools visited		0	4	0	4	64	135
Total		0	7	0	7	150	253
Pools by rank							
Pools with fish		0	1	0	1	25	33
Not visited	1	0	0	0	0	28	28
	2	0	0	0	0	46	55
	3	0	3	0	3	12	35
Visited	4	0	0	0	0	4	4
	5	0	0	0	0	10	15
	6	0	2	0	2	11	27
	7	0	0	0	0	11	25
	8	0	1	0	1	2	21
	9	0	0	0	0	1	5
	10	0	0	0	0	0	5
Total		0	7	0	7	150	253

Figure 7. (Next page) Locations of vernal pools, amphibian hotspots, and connecting corridors relative to protected land within the Queen's River watershed. Ranked pools are identified either as triangles, indicating that they were not visited and were ranked by upland forest cover within 300 m only; or as circles, indicating that they were visited and were ranked by pool size, hydroperiod, and upland forest cover. Squares represent pools that likely support fish and were not ranked. If pools are very close together, symbols may overlap.



A
X
B
C
D
Y
Z
E
F
N
Kilometers
0 1 2 3
Pool Rank
1
2
3
4
5
6
7
8
9
10
Fish
Hotspot
Corridor
Protected Land
ASRI
TNC
RIDEM
Town land trust
Other (easement)

Figure 8. (Next page) Locations of vernal pools, amphibian hotspots, and connecting corridors relative to land cover types within the Queen's River watershed. Ranked pools are identified either as triangles, indicating that they were not visited and were ranked by upland forest cover within 300 m only; or as circles, indicating that they were visited and were ranked by pool size, hydroperiod, and upland forest cover. Squares represent pools that likely support fish and were not ranked. If pools are very close together, symbols may overlap.



A
X
B
C
D
Y
Z
E
F
N
Kilometers
0
1
2
3
Pool rank
1
2
3
4
5
6
7
8
9
10
Fish
River
Hotspot
Corridor
Developed
Open land
Upland forest
Water
Wetland

hotspot are currently protected, predominantly within ASRI's Fisherville Brook Wildlife Refuge (Fig. 7).

Hotspot B. - Straddles Route 102, just west of South Road, in the northeastern part of the watershed (Fig. 6). This hotspot lies entirely within the town of Exeter. Upland forest covers 345 ha (74 %) of the 464-ha area (Table 3, Fig. 8). Hotspot B includes 21 pools: 5 high-ranking, 7 of intermediate rank, and 2 low-ranking; 4 pools with fish; and 3 pools that were not visited. Pool density in hotspot B is relatively high, at 4.5 pools/sq km. Almost 200 ha (42%) of this hotspot are currently protected by TNC (Fig. 7).

Hotspot C. - Covers 226 ha and is located south of Route 102 and east of Tripps Corner Road in the town of Exeter (Fig. 6). Upland forest (187 ha, 83%) dominates the landscape here (Table 3, Fig. 8). Of the six pools located within this hotspot, three are high-ranking, two were not visited, and one likely supports fish. The density of pools is 2.7/sq km. The hotspot includes a 58-ha parcel owned by TNC (Fig. 7); thus 26% of the hotspot is protected.

Hotspot D. - Located north of Mail Road, and west of South Road, within the town of Exeter (Fig. 6). Covering 197 ha, this is the smallest hotspot we identified. Upland forest is relatively sparse, but still accounts for 43% of the land cover (Table 3, Fig. 8). However, the percentage of wetland in hotspot D (42%) is greater than in any of the other hotspots (Table 3). Developed land covers only 2% of hotspot D, but much of its eastern border is urbanized (Fig. 8). Hotspot D overlaps ASRI's Marion Eppley Wildlife Sanctuary (Fig. 7). Overall, 112 ha (57%) of this hotspot are currently protected. Thirteen pools were identified in hotspot D: 3 high-ranking pools, 3 pools of intermediate rank, 1 low-ranking pool, 2 pools with fish, and 4 pools that were not visited during the study (Table 3). The density of pools is greatest in this hotspot (6.6/sq km).

Hotspot E. - Located along the southwestern edge of the watershed, within the towns of Richmond, Exeter, and South Kingstown (Fig. 6). This is the largest hotspot, encompassing 606 ha. Upland forest covers 426 ha (70%) of hotspot E (Table 3, Fig. 8) and relatively little—105 ha (17%)—of the area is currently protected (Table 3, Fig. 7). The relative abundance of developed land is greatest in this hotspot (10%); most of it occurs as an elongated island near the center (Fig. 8). Hotspot E includes 32 pools, 17 of which we were unable to visit. Five of the visited pools are high-ranking, 9 are of intermediate rank, and 1 is low-ranking (Table 3). None of the pools that we visited is likely to support fish. Pool density in hotspot E is 5.3/sq km. The northeastern corner of this hotspot is less than 0.5 km from the northwestern corner of hotspot F (Fig. 6).

Hotspot F. - Located north of Route 138 and south of Mail Road along the eastern edge of the watershed in Exeter and South Kingstown (Fig. 6). This hotspot covers 398 ha, 228 (57%) of which are upland forest and 146 (37%) of which are wetland (Table 3, Fig. 8). Of the 12 pools identified, 5 are high-ranking, 6 are of intermediate rank, and 1 was not visited; none of the pools that we visited are low-ranking or are likely to support fish (Table 3). The density of pools here is 3.0/sq km. Eighty-eight percent of hotspot F is currently protected; most is contained within ASRI's Marion Eppley Wildlife Sanctuary (Fig. 7).

Corridors Connecting Hotspots

The corridors that link the six hotspots cover 1,100 ha, of which 452 ha (41%) are currently protected (Table 3, Fig. 7). Each corridor contains very little developed land (4% or less); as in the hotspots, the most abundant land cover type is upland forest (62-84%). No vernal pools were identified in corridor X, which links hotspots A and B across 228 ha of mostly upland forested landscape (Figs. 6, 8). Forty-eight percent of the land in corridor X (109 ha) is protected (Table 3). Corridor Y, which comprises 856 ha, connects four hotspots (B, C, D, and F) and includes 7 pools: 1 high-ranking, 2 of intermediate rank, 3 that were not visited, and 1 with fish (Table 3, Fig. 6). Forty percent of corridor Y overlaps ASRI's Marion Eppley Wildlife Sanctuary and other protected areas (Table 3, Fig. 7). No vernal pools were identified in corridor Z, which covers only 26 ha. This small corridor connects hotspots E and F in an area dominated by upland forest and agricultural land (Table 3, Fig. 8).

Land Cover and Pools Outside of Hotspots and Corridors

More than 6,000 ha within the Queen's River watershed lie outside of hotspots and corridors. Upland forest occupies 51% of this area, while developed land accounts for 16% (Table 3).

Only 13% of this area is currently protected. We identified 150 confirmed or potential vernal pools outside of the hotspots and corridors; of those, we visited only 64. Twenty-five of the 64 visited pools likely support fish, while 14 others are low-ranking, 22 are of intermediate rank, and 3 are high-ranking (Table 3).

Appendix B provides a map that identifies each of the watershed's vernal pools by number. Appendix C presents detailed data for each pool.

DISCUSSION

Queen's River Watershed as Amphibian Habitat

The quality of pool-breeding amphibian habitat in the Queen's River watershed is relatively high, particularly compared to suburban and urban areas of Rhode Island. This is due to its high forest cover, abundance of wetlands, and limited land development. Of the 102 fishless pools that we were able to visit throughout the watershed, a very high proportion (81%) ranks high or intermediate in terms of their potential ability to support a diverse, highly productive amphibian community. A relatively long hydroperiod, moderate to large size, and extensive upland forest cover within the surrounding area characterize most of these pools.

We identified six specific geographic areas, or hotspots, with especially high potential for meeting both aquatic and terrestrial habitat requirements of pool-breeding amphibians—especially wood frogs and spotted salamanders—at the landscape scale. These hotspots were fairly easy to identify once the pools had been ranked and the ranks were displayed in map form (Fig. 6). Their common features include clusters of high-ranking pools, high upland forest cover within reported migration distances for wood frogs and mole salamanders (Semlitsch and Bodie 2003), and a low percentage of developed land. These hotspots encompass only 24% of the land in the Queen's River watershed, but they include nearly 40% of all vernal pools identified, including the great majority (87%) of the high-ranking, fishless pools that we visited and more than half of the fishless pools of intermediate rank. There is little doubt that these are hotspots for pool-breeding amphibians.

The six hotspots are linked by easily identifiable corridors that also have lower levels of land development and more extensive forest cover than the watershed as a whole. Combined, the hotspots and corridors account for about 3,400 ha, or a little more than one-third of the land in the watershed. The high quality of the habitat in both the hotspots and the corridors is due, in part, to well-planned land protection efforts by ASRI, TNC, and RIDEM. Forty-four percent of the land in the hotspots and 41% of the land in the corridors is already protected through acquisition in fee or conservation easements, as opposed to 24% watershed-wide. The low incidence of forest fragmentation and the high percentage of protected land make the Queen's River watershed unique statewide.

A Strategy for Habitat Protection

While it is doubtful that past land conservation decisions have been based primarily on strategies to protect pool-breeding amphibians, much of the protected land in this watershed coincides with areas of prime amphibian habitat. Many of these parcels undoubtedly are highly valued for other environmentally related reasons, including maintenance of wetlands, protection of surface water quality for habitat or recreation, aquifer protection, and preservation of rare flora or fauna. In many ways, the results of this study confirm the wisdom of the land protection decisions already made in the Queen's River watershed. Overlaying the amphibian hotspots and connecting corridors identified in this study and the protected lands in the watershed clearly points out the gaps—those unprotected areas that should be targeted for future land conservation efforts (Fig. 7). We believe that our findings—based on the biology of these animals—can be used in conjunction with other natural heritage data and the spatial distribution of already protected lands to justify continuing land conservation efforts in these same areas.

In order to maintain pool-breeding amphibian populations at the landscape scale, the first priority should be conservation of currently unprotected pools and surrounding upland forests within the six designated hotspots. Within a hotspot, pool ranks should be helpful in prioritizing efforts at a finer scale. In such a highly forested setting, high ranks (8-10) indicate long hydroperiods and moderate to large pool size, both of which are correlated with high egg-mass counts of spotted salamanders and wood frogs (Skidds et al. 2007). In dry years or wet years, such pools are major sources of new recruits for the amphibian community (Mitchell 2005). Acquisition in fee would offer the best, long-term guarantee of habitat preservation in the hotspots that we have identified.

Throughout this study we have placed major emphasis on pools with moderate to long hydroperiods (Classes 2-4), but Class 1 pools also may make important contributions to wood frog productivity in wetter than average years, when hydroperiods are longer than average. Even in years of average precipitation, Class 1 pools may provide critical habitat for rare species such as the Eastern spadefoot toad (*Scaphiopus h. holbrookii*), which is able to complete the aquatic phase of its life cycle in as few as 14-60 days (Wright and Wright 1949). For reasons such as these, some ecologists (e.g., Semlitsch 2000) have argued that, to effectively manage the pool-breeding amphibian community at the landscape level, preservation of pools with a wide range of hydroperiods is necessary. The hotspots that we have identified in the Queen's River watershed contain pools with such a diversity of hydroperiods. Information on rare species and rare habitats may be found in the Rhode Island Natural Heritage Program database, which is managed by the Rhode Island Natural History Survey.

Given limited funds, decisions to prioritize conservation efforts among hotspots could be based on: (1) the imminent threat of land development (e.g., in hotspots D or E, where urbanization is farther along than in other areas); (2) the proportion of high-ranking pools present (e.g., hotspot A, 67%; hotspot C, 50%); or (3) the extent of land not yet protected in the hotspot (e.g., 83% in hotspot E, 74% in hotspot C). An argument also might be made for favoring hotspots with high—or low—pool density. Hotspots with high pool density, such as E (5.3 pools/sq km) and D (6.0 pools/sq km), are valuable because of the abundance and diversity of breeding habitat that they provide. On the other hand, amphibian populations in hotspots with low pool density (e.g., hotspot C, 2.7 pools/sq km; hotspot A, 2.9 pools/sq km; or hotspot F, 3.0 pools/sq km) are more likely to suffer significant declines if even a single pool is lost as a result of a land use change (Calhoun et al. 2003).

Land conservation in the corridors connecting hotspots also will benefit pool-breeding amphibians by providing high-quality terrestrial habitat that will allow animals to disperse among hotspots, thus enhancing the long-term persistence of the species in the watershed. Vernal pools within such corridors may provide "stepping-stones" for animals repopulating regions where populations have declined or died out due to drought or disease, for example. Creation of pools in corridors where there are few or none might enhance this function, thereby stabilizing population levels throughout the watershed. Protection via either fee acquisition or perpetual easements should be effective in corridors.

Vernal pools that occur outside of hotspots and corridors also may provide suitable—or even highly productive—breeding sites for vernal pool species as long as there is ample forested upland nearby and human impacts are minimal. As in hotspots and corridors, protection of individual pools may be prioritized using their ranks. Pools with long hydroperiods and moderate to large size, but located in an agricultural or other open setting, also have the potential to be important habitats for pool-breeding amphibians if the surrounding land can be reforested. Where land acquisition and easements are either not feasible or not justifiable, the quality of vernal pools and surrounding terrestrial habitats should be safeguarded through the use of best management practices (Calhoun and deMaynadier 2001, Calhoun and Klemens 2002).

Evaluation of the Approach and Future Applications

This study was a pilot project designed to test the feasibility of prioritizing amphibian habitat protection at the watershed scale using a science-based approach. The basic procedure involved seven steps: (1) identifying potential vernal pools using aerial photography, (2) seeking landowner permission to access potential vernal pools, (3) conducting preliminary field visits to potential vernal pools, (4) conducting follow-up visits to collect data for hydroperiod estimation, (5) performing landscape-scale analyses using GIS and publicly available datasets, (6) ranking suitability of individual pools for pool-breeding amphibians, and (7) delineation of amphibian hotspots and connecting corridors. We believe that this effort was successful and that the findings will be helpful in targeting future land conservation efforts in the Queen's River watershed. At the same time, it is important to review the strengths, limitations, and unique aspects of our approach for the benefit of those who might undertake similar projects in the future.

First, our work benefited greatly from the Pawcatuck River watershed vernal pool inventory completed several years ago by TNC. Of the 253 vernal pools in this study, 228 (90%) were identified by TNC. We identified 11 additional pools in the field and another 14 through interpretation of digital, color, orthophotography. It is possible that we and TNC failed to detect other pools that were either very small or hidden under a coniferous forest canopy. Accurate detection of vernal pools from aerial photographs has been a topic of discussion among biologists for several years (Stone 1992, Brooks et al. 1998, Calhoun et al. 2003). Nevertheless, the TNC dataset was an extremely valuable tool for designing and carrying out both this study and our earlier research in the Pawcatuck River watershed.

The availability of wetlands and land use/land cover datasets through RIGIS also greatly aided our work. The source photography for those two datasets was from 1988 and 1995, respectively, however, and it is highly likely that both upland forest cover and the area of developed land around certain pools, and in the hotspots and connecting corridors, have changed since then. Although we had insufficient time or resources to update those datasets, a cursory review of the entire watershed using the digital, color, orthophotography convinced us that any such changes would have had a minimal impact on our results.

Still another great advantage in our work was the availability of pool hydroperiod estimation methods, which we had developed during four years of vernal pool research in the Pawcatuck watershed, as well as project personnel who had developed or used those methods. A research associate with a Master's degree that focused on vernal pool ecology performed the bulk of the work. Both he and his part-time, post-baccalaureate assistant had considerable academic training and field experience in wetland science and GIS. Project duration was approximately 12 months, but considerably more time would have been required if the above datasets had not been available or if project personnel had been less experienced.

Site visits and collection of field data were essential to assess the presence of fish and to estimate pool size and hydroperiod for fishless ponds. We were able to visit 33 pools once (those believed to support fish) and 102 pools at least twice to obtain required field data in this 9,488-ha watershed. We were disappointed that agreement between hydroperiod estimates generated by the Skidds model and the plant method (39%) was not better, but we felt comfortable exercising our best professional judgment, in combination with—or in the absence of—those estimates, to arrive at a final hydroperiod estimate for each pool. The prior experience of project personnel was a major reason for our confidence in the accuracy of the final estimates.

We are also satisfied that the three variables that we employed for pool ranking—pool hydroperiod, pool size, and upland forest cover within 300 m of each pool—were well chosen, based on our own research and that of other scientists in the field. These variables were selected because of their influence on reproductive effort (egg-mass counts) of wood frogs and spotted salamanders. However, high-ranking pools and hotspots identified in this study should represent valuable habitat for most pool-breeding amphibians, simply because long hydroperiods and the absence of fish are key prerequisites for pool occupancy for most species and thus, for amphibian diversity. As noted earlier, identification of amphibian hotspots and connecting corridors was straightforward once the pools had been ranked and the rankings were displayed on a map that also showed forest cover and other land use and land cover types.

We identified 253 potential vernal pools in the Queen's River watershed, but were able to visit only 53% (135) of them; therefore, our final results are based on a sample of the pools, not the entire population. Although we lacked field data for many pools, we did assess surrounding upland forest cover for all pools using RIGIS data. Some pools that we did not visit undoubtedly supported fish and thus were poor pool-breeding amphibian habitat. Because we were unable to determine if a pool supported fish without a field visit, we assumed all unvisited pools to be potentially productive for vernal pool amphibians and we incorporated them into hotspots when their locations warranted. If possible, future researchers or managers should attempt to estimate the potential productivity of the pools that we could not ground-truth.

We contacted 134 landowners, including private individuals, businesses, and nongovernmental conservation organizations, as well as local and state governments, but were unable to locate, or solicit responses from, 36 landowners. Of the 98 landowners who responded, 61 (62%) allowed us access to their property. We did not ask landowners to explain decisions to grant or deny access, but some responses included reasons. Some landowners who allowed access were already familiar with vernal pools and pool-breeding amphibians and were interested in our research; in some instances, they offered valuable information about the presence of certain species. Other willing landowners were interested in learning more about our study and requested copies of our results. A few landowners who denied us access to their property simply expressed concern about having people on their land. Although we tried to explain that our study was in no way related to regulatory action, some landowners were concerned that our results might lead to further restriction of their property rights. During previous field studies, we have found that roughly 50% of landowners are willing to cooperate. Although a much higher rate is desirable, it does not appear to be achievable. However, we are confident that a larger sample size would not have changed the number or location of hotspots significantly.

Given the relatively high percentage of protected land in the Queen's River watershed and the greater access to those properties, our results were slightly biased toward pools located on protected land. Of the 253 potential vernal pools in the watershed, 20% (50) are located on protected land; of the 135 pools that we visited, 27% (37) are on protected land. This difference, in turn, led to a bias in the delineation of our hotspots, which focused on high-ranking pools that had been field-checked. The occurrence of greater contiguous tracts of upland forest within conservation areas may also have contributed to a bias towards identifying hotspots and corridors within currently protected lands. That bias was expected, however, and simply underscores the importance of protecting undeveloped land before it becomes fragmented.

The two most time-consuming steps in this project were our attempts to secure landowner permission for access to potential vernal pools and collection of field data needed to estimate pool hydroperiods. Both steps are prerequisite to a scientifically sound ranking of pools and identification of amphibian hotspots. As a result, significant streamlining of the prioritization process in future studies would be difficult to accomplish. A “first-cut” or preliminary identification of potential hotspots might be accomplished by identifying those areas where vernal pools are numerous (e.g., Burne 2001) and upland forest cover is extensive. If pools are locally numerous, then one would expect several hydroperiod classes to be represented, including some Class 3 and Class 4 fishless ponds, as well as several sizes of ponds. This process would require the overlay of forest cover and vernal pool datasets in GIS—if they were available—or new photo-interpretation of these features on recent, large-scale aerial photographs. However, field data still are essential if ponds are to be ranked according to potential productivity.

During our study in the Queen's River watershed, we were unable to conduct egg-mass counts or to determine actual 2006 hydroperiods at most of the ponds that we visited. Even though both features may vary significantly among years (Mitchell 2005), collection of such data, even during a single year, would permit tentative conclusions to be drawn about probable differences in productivity among the pools in the study. We recommend collection of such data in future prioritization studies, if possible.

We are confident that the approach that we piloted in this study can be applied successfully in other watersheds, both in Rhode Island and elsewhere, but the process of pool ranking and hotspot identification will take considerably longer if a pool inventory, GIS data on land use and land cover, and hydroperiod estimation methods are not available beforehand. Ideally, project personnel should have prior experience in vernal pool ecology and GIS or receive in-field training in advance of project work.

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Appendix A. Landowner contact procedures.

To identify vernal pool landowners, we contacted and visited municipal governments for South Kingstown, Exeter, West Greenwich, and Richmond. Planning departments for the Towns of Richmond and South Kingstown supplied us with GIS data layers containing landowner information from which we identified the owners of potential vernal pools. We visited Exeter and West Greenwich town halls and identified landowners using aerial photos, street maps, and the town's plat and lot maps.

We sent the first letter to many landowners in early March 2006 (see Letter 1 below). The letter, which was printed on letterhead of the URI Department of Natural Resources Science, included a self-addressed, stamped return envelope and a 3" x 5" response card (see below). Within one week, we began receiving responses, which continued for the next several months as we continued to contact landowners.

We telephoned all landowners with a publicly listed telephone number who had not responded within two weeks from the first mailing. If we were unable to reach them after at least three attempts by phone, we sent a second letter restating our request for property access (see Letter 2 below). Once again, we included a self-addressed, stamped envelope and a response card. Our final approach to reach landowners from whom we still had received no response was to visit them in person at the street address where the letters had been sent.

We attempted to introduce ourselves to all landowners who had given us permission to access their property. If landowners were not at home during our visits, we left a note in an obvious location (e.g., in a mail box, door jamb) informing them of our visit (see Drop-off note below).

Letter 1

<<name>>
<<address1>>
<<address2>>

<<date>>

Dear <<name>>«Owner»,

I am working with Dr. Frank Golet at the University of Rhode Island on a survey of seasonal ponds and the animals that use them. Our review of maps and aerial photographs suggests that your property may contain one or more of these ponds. I am writing to ask if we may include your pond(s) in our study and if we might have your permission to visit them periodically.

The study encompasses all of the seasonal ponds in the Queen's River Watershed. In a nutshell, we hope to determine which ponds provide the best habitat for frogs and salamanders and why. Visits would occur approximately once a month between this spring and fall and would generally involve identifying plants and animals in the pond, measuring the size and maximum depth of the pond, and determining when (or if) the pond has dried completely.

Permission to access the sites is essential to the survey. In the upcoming weeks I would like to contact you by telephone and to answer any questions you may have about the research. I have enclosed a response card and a self-addressed, stamped envelope for your ease of responding. I really appreciate your taking the time to consider this request.

If you have any questions, comments, or concerns please contact me by e-mail at jmit1344@postoffice.uri.edu or Frank Golet at (401) 874-2916. I can also be reached at the address below.

Sincerely,

Jon Mitchell
Research Associate
Dept. of Natural Resources Science – URI
105 Coastal Institute – Kingston
1 Greenhouse Road
Kingston, RI 02881

Letter 2

<<name>>
<<address1>>
<<address2>>

<<date>>

Dear <<name>>«Owner»,

In the past few weeks I have attempted to contact many landowners in the Queen's River Watershed to request cooperation in a survey of seasonal ponds that I am conducting at the University of Rhode Island. I have tried to reach you by letter and by phone, but, unfortunately, have been unsuccessful, so I thought I would try once more.

As I wrote in the last letter, I am conducting a survey of seasonal ponds and the animals that may inhabit them throughout the Queen's River Watershed. Based on a review of maps and aerial photographs, I believe that your land may contain one or more of these ponds. The success of the study depends upon being able to visit the sites approximately once a month between the spring and fall of this year. During the visits I would collect information on the plants and animals present, the area and depth of the pond, and the water level.

We respectfully request your cooperation. You can contact me by e-mail at jmit1344@postoffice.uri.edu or my supervisor, Dr. Frank Golet, at (401) 874-2916. Additionally, I have enclosed a postcard and self-addressed, stamped envelope for your ease of responding.

Thank you for your time and I look forward to hearing from you.

Sincerely,

Jon Mitchell
Research Associate

Response card

Comments can be made on the back of this card or directed to
Frank Golet at (401) 874-2916 or to
Jon Mitchell at jmit1344@postoffice.uri.edu.

__ Yes, researchers from URI involved in the study of seasonal ponds are welcome to access my property.

__ No, researchers from URI are NOT welcome to access my property.

__ Please contact me regarding access to my property at
phone number: e-mail:
address:

Drop-off note

Hello

We recently contacted you via telephone and/or mail and received permission to access your property for a study of seasonal ponds we are conducting. On our first visit to the site we stopped by to thank you for your willingness to participate in the study and answer any questions or concerns you may have about our project. In the upcoming months, you may see us arrive in a pick-up truck with a URI emblem on the side. We will visit the ponds for varying periods of time every few weeks. If you have any questions or concerns, please feel free to call Frank Golet at (401) 874-2916 or e-mail Jon Mitchell at jmit1344@postoffice.uri.edu.

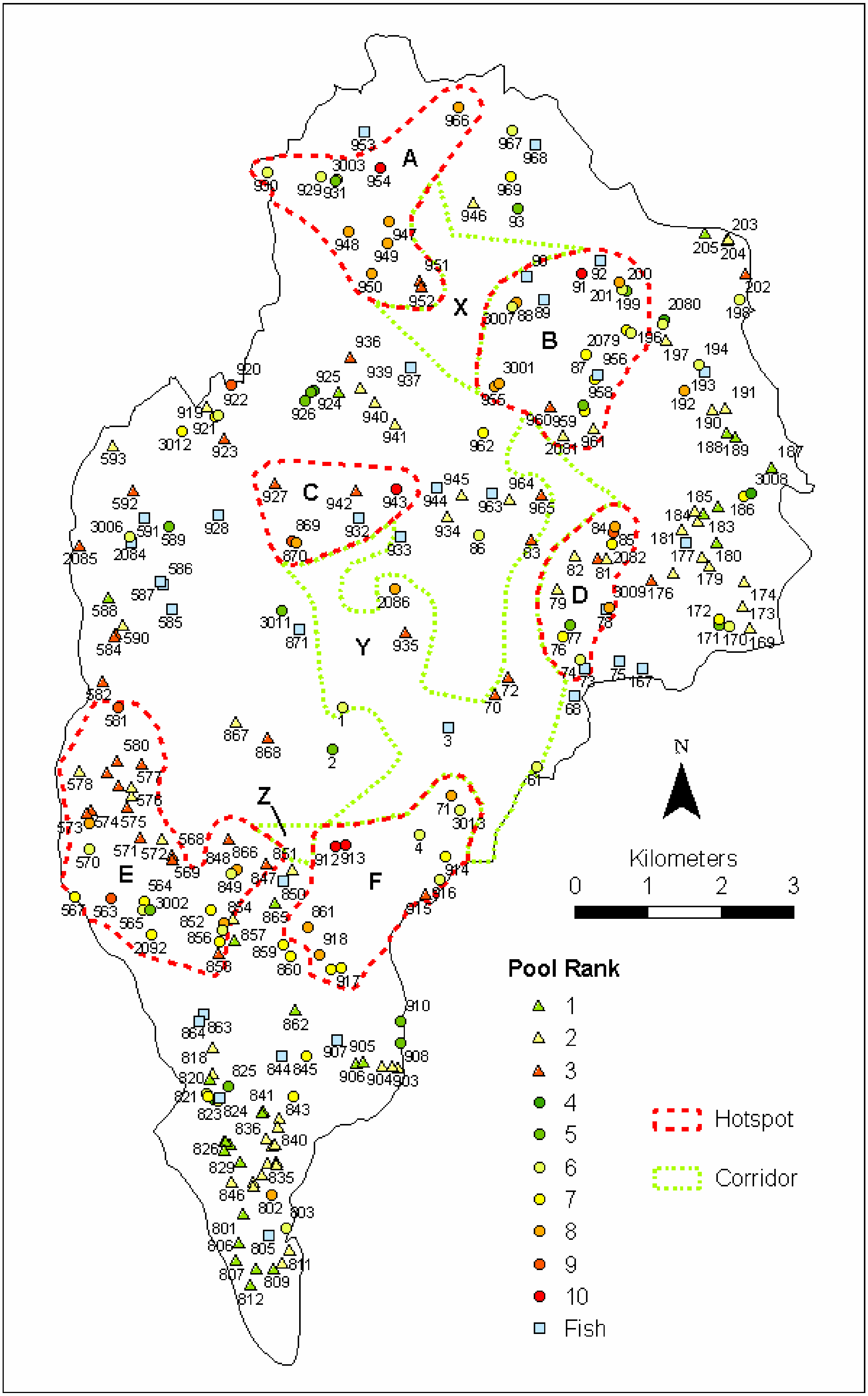
Thanks-

Frank Golet, Principal Investigator

Jon Mitchell, Research Associate

Mike Narcisi, Research Assistant

Appendix B. (Next page) Identification of vernal pools within the Queen's River watershed by pool number. Ranked pools are identified either as triangles, indicating that they were not visited and were ranked by upland forest cover within 300 m only; or as circles, indicating that they were visited and were ranked by pool size, hydroperiod, and upland forest cover. Squares represent pools that likely support fish and were not ranked. If pools are very close together, symbols may overlap and may not be numbered due to insufficient space.


A
B
C
D
E
F
X
Y
Z
N
Kilometers
0
1
2
3
Pool Rank
1
2
3
4
5
6
7
8
9
10
Fish
Hotspot
Corridor

Appendix C. Data for individual vernal pools, sorted by visitation status, fish presence, and pool identification number.

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
1	Yes	No	Corridor Y	6	0.110	56.0
2	Yes	No		5	0.019	36.1
4	Yes	No	Hotspot F	6	0.056	47.6
61	Yes	No	Corridor Y	6	0.038	64.9
71	Yes	No	Hotspot F	8	0.024	67.1
74	Yes	No	Hotspot D	6	0.894	29.4
76	Yes	No	Hotspot D	7	0.094	24.7
77	Yes	No	Hotspot D	5	0.053	18.0
84	Yes	No	Hotspot D	9	0.409	63.4
85	Yes	No	Hotspot D	8	0.064	67.2
86	Yes	No		6	0.021	42.1
87	Yes	No	Hotspot B	7	0.114	80.4
88	Yes	No	Hotspot B	8	0.233	61.9
91	Yes	No	Hotspot B	10	0.161	71.7
93	Yes	No		5	0.024	87.3
170	Yes	No		6	0.161	26.3
171	Yes	No		5	0.126	41.7
172	Yes	No		7	0.301	55.4
186	Yes	No		7	0.391	17.3
192	Yes	No		8	0.070	49.8
194	Yes	No		6	0.162	25.9
195	Yes	No	Hotspot B	6	0.149	52.9
196	Yes	No		6	0.041	46.9
198	Yes	No		6	0.054	55.3
199	Yes	No	Hotspot B	5	0.018	49.1
200	Yes	No	Hotspot B	6	0.058	43.2

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
1	2	0		65	04	7	Exeter
2	2	0	small stream	65	04	7	Exeter
4	2	0	Eppley Sanctuary	66	02	1	Exeter
61	2	0	drive-by	71	04	13	Exeter
71	3	0	Eppley Sanctuary	71	01	1	Exeter
74	2	1		67	04	1	Exeter
76	3	1		67	04	1	Exeter
77	2	1		67	04	1	Exeter
84	4	2	Queen's River Preserve	51	03	1	Exeter
85	4	2	Queen's River Preserve	51	03	1	Exeter
86	4	0	small stream	50	05	4	Exeter
87	2	0	TNC; alluvial	25	04	1	Exeter
88	2	0		11	02	1	Exeter
91	3	0	Queen's River Preserve	11	02	3	Exeter
93	1	0	Queen's River Preserve	60	1	0	West Greenwich
170	2	3	stream	62	03	1	Exeter
171	1	2		62	03	1	Exeter
172	2	2		62	03	1	Exeter
186	4	0		39	01	1	Exeter
192	3	0	detention basin	25	05	7	Exeter
194	2	1	stream	25	5	26	Exeter
195	2	1	TNC	12	01	1	Exeter
196	4	2		25	03	18	Exeter
198	2	0		13	03	8	Exeter
199	2	2		12	05	2	Exeter
200	2	2		12	05	2	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
201	Yes	No	Hotspot B	8	0.062	42.0
563	Yes	No	Hotspot E	9	0.386	48.6
564	Yes	No	Hotspot E	7	0.190	45.2
565	Yes	No	Hotspot E	6	1.096	51.0
567	Yes	No	Hotspot E	7	0.147	80.1
570	Yes	No	Hotspot E	6	0.078	43.4
574	Yes	No	Hotspot E	8	0.481	61.8
581	Yes	No	Hotspot E	9	0.116	61.7
589	Yes	No		5	0.022	73.0
802	Yes	No		8	0.059	45.3
803	Yes	No		6	0.118	15.0
821	Yes	No		6	0.075	45.3
822	Yes	No		4	0.033	36.0
823	Yes	No		6	0.055	33.8
825	Yes	No		5	0.032	37.5
843	Yes	No		7	0.429	33.7
845	Yes	No		7	0.176	25.0
848	Yes	No	Hotspot E	8	0.192	93.4
849	Yes	No	Hotspot E	6	0.078	86.5
852	Yes	No	Hotspot E	7	0.117	76.4
854	Yes	No	Hotspot E	8	0.096	56.8
855	Yes	No	Hotspot E	6	0.106	61.0
856	Yes	No	Hotspot E	7	0.267	66.7
859	Yes	No		7	0.268	18.9
860	Yes	No		7	0.450	16.0
861	Yes	No	Hotspot F	8	0.554	41.9

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
201	3	2		12	05	2	Exeter
563	3	0	streamside	04E	003	034	Richmond
564	2	1	streamside	04E	003	044	Richmond
565	1	1		04E	003	043	Richmond
567	2	1	streamside	04E	001	000	Richmond
570	2	0		04E	002	025	Richmond
574	2	2		03E	020	003	Richmond
581	3	0		02E	013	002	Richmond
589	1	0	channel	47	03	3	Exeter
802	3	3			20	19	South Kingstown
803	4	1			13	ROAD	South Kingstown
821	2	5		06F	014	003	Richmond
822	1	5		06F	014	003	Richmond
823	2	4		06F	014	004	Richmond
825	2	5	floodplain		12	39	South Kingstown
843	2	0			12	38	South Kingstown
845	4	0		7	3	16	South Kingstown
848	2	1		1	3	1	South Kingstown
849	1	1		1	1-3	2	South Kingstown
852	2	1		4	4	21	South Kingstown
854	3	5		4	4	21	South Kingstown
855	1	4		4	4	21	South Kingstown
856	1	4		4	4	21	South Kingstown
859	4	1		4	4	9	South Kingstown
860	4	1		4	3	1	South Kingstown
861	4	0		4	3	13	South Kingstown

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
869	Yes	No	Hotspot C	9	0.065	85.4
870	Yes	No	Hotspot C	8	0.211	84.9
908	Yes	No		5	0.035	53.3
910	Yes	No		5	0.018	38.6
912	Yes	No	Hotspot F	10	0.587	80.8
913	Yes	No	Hotspot F	10	0.277	78.6
914	Yes	No	Hotspot F	7	0.245	53.5
916	Yes	No	Hotspot F	6	0.027	63.0
917	Yes	No	Hotspot F	7	0.010	51.5
918	Yes	No	Hotspot F	8	0.143	50.2
920	Yes	No		9	0.230	49.1
921	Yes	No		7	0.370	41.3
922	Yes	No		6	0.058	37.8
924	Yes	No		4	0.028	36.2
925	Yes	No		5	0.009	40.3
926	Yes	No		5	0.065	35.3
929	Yes	No	Hotspot A	6	0.130	59.3
930	Yes	No	Hotspot A	6	0.084	74.2
931	Yes	No	Hotspot A	6	0.044	57.0
943	Yes	No	Hotspot C	10	0.302	83.4
947	Yes	No	Hotspot A	8	0.371	84.5
948	Yes	No	Hotspot A	8	0.168	80.2
949	Yes	No	Hotspot A	8	0.060	68.2
950	Yes	No	Hotspot A	8	0.164	96.1
954	Yes	No	Hotspot A	10	0.328	63.4
955	Yes	No	Hotspot B	8	0.026	65.7

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
869	3	2	TNC	49	01	4	Exeter
870	2	2	TNC	49	01	4	Exeter
908	2	0		13	1	36	South Kingstown
910	2	1			8	15	South Kingstown
912	3	1	Eppley Sanctuary	66	02	1	Exeter
913	3	1	Eppley Sanctuary	66	02	1	Exeter
914	2	0	headwater	76	03	11	Exeter
916	2	1	Eppley Sanctuary	66	02	1	Exeter
917	3	1		4	3	13	South Kingstown
918	3	1		4	3	13	South Kingstown
920	3	0		22	02	31	Exeter
921	2	2		35	01	5	Exeter
922	2	2		35	01	4	Exeter
924	1	2		22	03	3	Exeter
925	2	2	dug hole	22	03	3	Exeter
926	1	2	marbled salamanders	22	03	3	Exeter
929	2	1		052	0002	00	West Greenwich
930	1	0	dug hole	051	0009	00	West Greenwich
931	4	1		052	0002	00	West Greenwich
943	3	0		36	03	3	Exeter
947	2	0	Fisherville	53	15	2	West Greenwich
948	2	0	Fisherville	52	1	0	West Greenwich
949	4	0	Fisherville	10	01	8	Exeter
950	2	0	Fisherville	10	01	1	Exeter
954	3	0	bog connection	053	0001	01	West Greenwich
955	3	0		24	01	11	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
957	Yes	No	Hotspot B	7	0.065	82.9
958	Yes	No	Hotspot B	5	0.019	80.0
959	Yes	No	Hotspot B	7	0.082	76.1
962	Yes	No		7	0.086	46.1
966	Yes	No	Hotspot A	8	0.355	90.4
967	Yes	No		6	0.087	65.1
969	Yes	No		7	0.104	87.3
2079	Yes	No	Hotspot B	7	0.105	62.5
2080	Yes	No		4	0.049	54.4
2082	Yes	No	Hotspot D	7	1.414	50.5
2086	Yes	No	Corridor Y	8	1.045	74.9
2092	Yes	No	Hotspot E	7	0.777	68.1
2093	Yes	No	Hotspot F	7	1.313	51.2
3001	Yes	No	Hotspot B	8	0.086	73.2
3002	Yes	No	Hotspot E	5	0.022	44.3
3003	Yes	No	Hotspot A	5	0.011	56.9
3004	Yes	No		7	0.489	42.2
3006	Yes	No		6	0.008	43.3
3007	Yes	No	Hotspot B	6	0.020	66.4
3008	Yes	No		4	0.060	21.0
3009	Yes	No	Hotspot D	8	0.090	35.9
3011	Yes	No		5	0.176	24.1
3012	Yes	No		7	0.058	67.7
3013	Yes	No	Hotspot F	6	0.043	89.6
3	Yes	Yes	Corridor Y	na	0.232	70.4
68	Yes	Yes		na	0.113	49.5

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
957	2	1	TNC; alluvial	25	04	1	Exeter
958	1	1	TNC	25	04	1	Exeter
959	2	2	TNC	25	04	1	Exeter
962	4	0		37	01	5	Exeter
966	2	0		055	0005	00	West Greenwich
967	1	0		059	0014	01	West Greenwich
969	2	0	Queen's River Preserve	60	1	0	West Greenwich
2079	2	1	TNC	12	01	1	Exeter
2080	1	2		25	03	19	Exeter
2082	2	4	Queen's River Preserve	51	03	1	Exeter
2086	2	0		60	01	17	Exeter
2092	1	0		04E	008	000	Richmond
2093	2	2	bog	4	3	13	South Kingstown
3001	4	0		24	1	11	Exeter
3002	2	0	no amphibians	04E	003	046	Richmond
3003	2	0	cow pond	052	0002	00	West Greenwich
3004	2	0		06F	014	003	Richmond
3006	4	0		01E	003	000	Richmond
3007	2	0	duck pond	11	02	1	Exeter
3008	1	0		39	1	1	Exeter
3009	3	0	Ladd School	67	04	01	Exeter
3011	1	0	fen	59	2	3	Exeter
3012	2	0		34	4	2	Exeter
3013	2	0	Eppley Sanctuary	71	03	7	Exeter
3	4	0	floodplain	66	01	1	Exeter
68	4	0	perm pond	67	01	6	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
73	Yes	Yes	Hotspot D	na	0.119	27.0
75	Yes	Yes		na	0.055	20.0
78	Yes	Yes	Hotspot D	na	0.031	34.3
89	Yes	Yes	Hotspot B	na	0.860	84.6
90	Yes	Yes	Hotspot B	na	2.259	63.0
92	Yes	Yes	Hotspot B	na	0.371	56.8
167	Yes	Yes		na	0.016	14.4
177	Yes	Yes		na	0.851	32.3
193	Yes	Yes		na	0.162	37.0
585	Yes	Yes		na	0.098	47.8
586	Yes	Yes		na	0.022	22.4
587	Yes	Yes		na	0.073	23.2
591	Yes	Yes		na	0.163	50.3
805	Yes	Yes		na	0.118	14.8
824	Yes	Yes		na	0.649	35.5
844	Yes	Yes		na	1.514	26.7
850	Yes	Yes		na	0.080	26.4
863	Yes	Yes		na	0.703	58.8
864	Yes	Yes		na	1.009	59.5
871	Yes	Yes		na	0.067	37.5
907	Yes	Yes		na	0.193	21.1
928	Yes	Yes		na	0.029	52.9
932	Yes	Yes	Hotspot C	na	1.416	56.2
933	Yes	Yes		na	6.190	29.3
937	Yes	Yes		na	0.136	51.3
944	Yes	Yes		na	0.102	37.9

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
73	4	1	perm pond	67	04	1	Exeter
75	4	0	stream	67	04	1	Exeter
78	4	0	pond	67	04	1	Exeter
89	4	0	perm stream	11	02	1	Exeter
90	4	0	perm stream	11	02	1	Exeter
92	4	0	perm pond	12	05	2	Exeter
167	4	0	perm pond	67	04	1	Exeter
177	4	1	large pond	51	02	11	Exeter
193	4	1	fountain in middle	25	5	29	Exeter
585	4	0	connected to lake	59	02	2	Exeter
586	4	1	connected to lake	59	02	2	Exeter
587	4	1	connected to lake	59	02	2	Exeter
591	4	0	streamside	47	02	13	Exeter
805	4	1	floodplain		20	19	South Kingstown
824	4	5	floodplain	06F	014	004	Richmond
844	4	0	connected to lake		12	39	South Kingstown
850	4	1	stream	4	1	12	South Kingstown
863	4	1	beaver present	05F	007	000	Richmond
864	4	1		05F	011	000	Richmond
871	4	0	dug pond	59	02	1	Exeter
907	4	0	stream alluvial	8	4	1	South Kingstown
928	4	0		48	01	4	Exeter
932	4	0	crawfish	49	05	7	Exeter
933	4	0		49	04	50	Exeter
937	4	0		23	03	15	Exeter
944	4	0		36	03	16	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
953	Yes	Yes		na	0.597	64.4
956	Yes	Yes	Hotspot B	na	1.628	76.8
963	Yes	Yes		na	0.081	58.2
968	Yes	Yes		na	0.315	46.4
2084	Yes	Yes		na	0.023	43.6
70	No	Ukn	Corridor Y	3	na	60.1
72	No	Ukn	Corridor Y	3	na	66.8
79	No	Ukn	Hotspot D	2	na	30.9
80	No	Ukn	Hotspot D	3	na	61.5
81	No	Ukn	Hotspot D	2	na	50.1
82	No	Ukn	Hotspot D	2	na	56.6
83	No	Ukn		3	na	69.6
169	No	Ukn		2	na	55.4
173	No	Ukn		2	na	45.5
174	No	Ukn		2	na	40.9
175	No	Ukn		2	na	39.2
176	No	Ukn		3	na	63.4
178	No	Ukn		2	na	37.2
179	No	Ukn		2	na	46.7
180	No	Ukn		1	na	10.5
181	No	Ukn		2	na	39.4
182	No	Ukn		2	na	31.3
183	No	Ukn		1	na	27.4
184	No	Ukn		2	na	30.6
185	No	Ukn		1	na	11.3
187	No	Ukn		1	na	13.0

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
953	4	0	Queen's River Preserve	54	6	1	West Greenwich
956	4	1	TNC	25	04	1	Exeter
963	4	1		37	02	10	Exeter
968	4	0		59	14	1	West Greenwich
2084	4	0		01E	003	000	Richmond
70	na	1	Eppley Sanctuary	66	03	5	Exeter
72	na	1	Eppley Sanctuary	66	03	5	Exeter
79	na	0	Eppley Sanctuary	50	03	1	Exeter
80	na	2	Eppley Sanctuary	51	03	21	Exeter
81	na	2	Eppley Sanctuary	51	03	21	Exeter
82	na	0	Eppley Sanctuary	50	03	1	Exeter
83	na	0		50	04	8	Exeter
169	na	1		63	01	1	Exeter
173	na	0		63	02	1	Exeter
174	na	0		52	01	1	Exeter
175	na	0		51	02	5	Exeter
176	na	0		51	01	8	Exeter
178	na	1		51	02	12	Exeter
179	na	1		51	02	12	Exeter
180	na	0		51	02	32	Exeter
181	na	2		51	02	31	Exeter
182	na	3		52	01	8	Exeter
183	na	3		52	01	8	Exeter
184	na	2		52	01	8	Exeter
185	na	1		52	01	8	Exeter
187	na	0		39	01	2	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
188	No	Ukn		1	na	6.3
189	No	Ukn		1	na	8.4
190	No	Ukn		2	na	32.7
191	No	Ukn		2	na	44.2
197	No	Ukn		2	na	33.6
202	No	Ukn		3	na	63.5
203	No	Ukn		2	na	38.6
204	No	Ukn		2	na	35.7
205	No	Ukn		1	na	29.3
568	No	Ukn	Hotspot E	3	na	63.6
569	No	Ukn	Hotspot E	3	na	68.5
571	No	Ukn	Hotspot E	3	na	61.8
572	No	Ukn	Hotspot E	2	na	58.7
573	No	Ukn	Hotspot E	3	na	69.5
575	No	Ukn	Hotspot E	3	na	70.2
576	No	Ukn	Hotspot E	2	na	58.1
577	No	Ukn	Hotspot E	2	na	54.7
578	No	Ukn	Hotspot E	2	na	44.8
579	No	Ukn	Hotspot E	3	na	70.4
580	No	Ukn	Hotspot E	3	na	88.1
582	No	Ukn		3	na	65.0
583	No	Ukn		3	na	71.4
584	No	Ukn		3	na	72.9
588	No	Ukn		1	na	25.6
590	No	Ukn		2	na	52.9
592	No	Ukn		3	na	78.5

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
188	na	1		26	1	1	Exeter
189	na	1		26	1	1	Exeter
190	na	1		39	02	4	Exeter
191	na	1		39	02	4	Exeter
197	na	2		25	03	13	Exeter
202	na	0		13	03	24	Exeter
203	na	3		13	03	21	Exeter
204	na	2		13	03	21	Exeter
205	na	2		13	03	21	Exeter
568	na	2		04E	005	000	Richmond
569	na	2		04E	005	000	Richmond
571	na	1		04E	002	000	Richmond
572	na	3		04E	004	000	Richmond
573	na	2		03E	017	000	Richmond
575	na	2		03E	012	001	Richmond
576	na	3		03E	012	03B	Richmond
577	na	3		03E	012	002	Richmond
578	na	0		03E	011	000	Richmond
579	na	2		03E	012	002	Richmond
580	na	1		03E	012	000	Richmond
582	na	0		02E	005	000	Richmond
583	na	2		02E	006	000	Richmond
584	na	2		02E	006	000	Richmond
588	na	0		01E	017	000	Richmond
590	na	2		02E	006	000	Richmond
592	na	0		34	03	2	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
593	No	Ukn		2	na	42.9
801	No	Ukn		1	na	18.1
806	No	Ukn		1	na	11.0
807	No	Ukn		1	na	11.3
808	No	Ukn		1	na	12.0
809	No	Ukn		1	na	24.1
810	No	Ukn		2	na	37.3
811	No	Ukn		2	na	42.0
812	No	Ukn		1	na	14.6
818	No	Ukn		2	na	44.0
819	No	Ukn		2	na	32.8
820	No	Ukn		1	na	29.5
826	No	Ukn		1	na	29.5
827	No	Ukn		1	na	26.6
828	No	Ukn		1	na	29.3
829	No	Ukn		1	na	25.2
830	No	Ukn		2	na	49.8
831	No	Ukn		2	na	52.3
832	No	Ukn		2	na	30.6
833	No	Ukn		2	na	31.5
834	No	Ukn		2	na	46.3
835	No	Ukn		2	na	50.4
836	No	Ukn		2	na	33.6
837	No	Ukn		2	na	44.3
838	No	Ukn		2	na	52.6
839	No	Ukn		2	na	46.5

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
593	na	0		34	02	2	Exeter
801	na	0		07F	006	001	Richmond
806	na	1		07F	006	001	Richmond
807	na	1		08F	007	000	Richmond
808	na	2			28	2	South Kingstown
809	na	2			28	2	South Kingstown
810	na	2			28	2	South Kingstown
811	na	1			28	2	South Kingstown
812	na	1		08F	009	000	Richmond
818	na	0		06F	003	000	Richmond
819	na	3		06F	020	020	Richmond
820	na	5		06F	018	000	Richmond
826	na	3			12	1	South Kingstown
827	na	3			12	1	South Kingstown
828	na	4			12	1	South Kingstown
829	na	2		07F	004	000	Richmond
830	na	4		07F	006	000	Richmond
831	na	4		07F	006	000	Richmond
832	na	6			20	21	South Kingstown
833	na	5			12	1	South Kingstown
834	na	5			12	1	South Kingstown
835	na	5			20	21	South Kingstown
836	na	3			12	1	South Kingstown
837	na	6			12	1	South Kingstown
838	na	6			12	1	South Kingstown
839	na	3			12	1	South Kingstown

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
840	No	Ukn		2	na	47.2
841	No	Ukn		1	na	17.7
842	No	Ukn		1	na	17.9
846	No	Ukn		2	na	46.7
847	No	Ukn	Hotspot E	3	na	63.2
851	No	Ukn		2	na	52.8
853	No	Ukn		2	na	36.8
857	No	Ukn		1	na	23.3
858	No	Ukn	Hotspot E	3	na	65.5
862	No	Ukn		1	na	1.0
865	No	Ukn		1	na	20.4
866	No	Ukn	Hotspot E	3	na	97.5
867	No	Ukn		2	na	45.0
868	No	Ukn		3	na	89.6
903	No	Ukn		2	na	52.3
904	No	Ukn		2	na	46.8
905	No	Ukn		1	na	26.9
906	No	Ukn		1	na	24.4
915	No	Ukn	Hotspot F	3	na	83.2
919	No	Ukn		2	na	46.0
923	No	Ukn		3	na	67.6
927	No	Ukn	Hotspot C	3	na	83.6
934	No	Ukn		2	na	52.3
935	No	Ukn	Corridor Y	3	na	73.7
936	No	Ukn		3	na	67.3
938	No	Ukn		1	na	26.2

Appendix C. (Continued).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
840	na	6			12	1	South Kingstown
841	na	3			12	1	South Kingstown
842	na	3			12	1	South Kingstown
846	na	2		07F	005	000	Richmond
847	na	0		74	01	5	Exeter
851	na	1		74	01	7	Exeter
853	na	3		4	4	20	South Kingstown
857	na	5		4	4	23	South Kingstown
858	na	2		4	4	1	South Kingstown
862	na	0		7	2	1	South Kingstown
865	na	0		4	1	6	South Kingstown
866	na	0		69	01	6	Exeter
867	na	0		64	01	23	Exeter
868	na	0		64	01	17	Exeter
903	na	3		13	1	44	South Kingstown
904	na	2		13	1	36	South Kingstown
905	na	2		13	1	42	South Kingstown
906	na	1		13	1	43	South Kingstown
915	na	1		75	03	5	Exeter
919	na	3		22	02	3	Exeter
923	na	0		35	01	3	Exeter
927	na	0		35	02	12	Exeter
934	na	0		50	05	27	Exeter
935	na	0		60	01	13	Exeter
936	na	0		23	04	13	Exeter
938	na	0		23	01	5	Exeter

Appendix C. (Continued).

Pool number	Visited?	Fish present or likely present?	Within hotspot or corridor?	Pool rank	Pool size (ha)	% upland forest w/i 300 m
939	No	Ukn		2	na	45.4
940	No	Ukn		2	na	40.5
941	No	Ukn		2	na	34.6
942	No	Ukn	Hotspot C	3	na	62.7
945	No	Ukn		2	na	55.1
946	No	Ukn		2	na	36.2
951	No	Ukn	Hotspot A	3	na	79.7
952	No	Ukn	Hotspot A	3	na	80.5
960	No	Ukn	Hotspot B	3	na	65.0
961	No	Ukn	Hotspot B	2	na	40.2
964	No	Ukn		2	na	41.9
965	No	Ukn		3	na	72.4
2081	No	Ukn	Hotspot B	2	na	58.5
2085	No	Ukn		3	na	74.2
2089	No	Ukn	Hotspot E	3	na	70.8
2090	No	Ukn	Hotspot E	3	na	65.0
2091	No	Ukn	Hotspot E	3	na	75.2
2094	No	Ukn		2	na	40.4
2095	No	Ukn		1	na	20.6

Appendix C. (Concluded).

Pool number	Hydroperiod class	No. pools w/i 300 m	Other notes	Map	Block	Lot	Town
939	na	1		23	01	5	Exeter
940	na	1		23	02	0	Exeter
941	na	0		36	02	3	Exeter
942	na	0		49	06	1	Exeter
945	na	0		50	05	11	Exeter
946	na	0		060	0001	00	West Greenwich
951	na	1	Fisherville	10	01	6	Exeter
952	na	1	Fisherville	11	01	1	Exeter
960	na	0		37	04	8	Exeter
961	na	1		38	01	3	Exeter
964	na	1		50	05	10	Exeter
965	na	0		37	03	4	Exeter
2081	na	0		37	04	1	Exeter
2085	na	0		01E	002	013	Richmond
2089	na	2		03E	017	000	Richmond
2090	na	3		03E	012	002	Richmond
2091	na	0		03E	012	000	Richmond
2094	na	3	fen	13	1	36	South Kingstown
2095	na	4			12	1	South Kingstown

Appendix D. Responses to stakeholder questions and comments.

Early in July of 2007, the RIDEM Office of Water Resources notified personnel from a wide range of federal and state agencies, municipal boards, and nongovernmental conservation organizations working in the Queen's River watershed of the availability of a draft version of this report and invited them to participate in a meeting on the topic on July 17 at URI. These stakeholders were given the opportunity to ask questions and to provide comments on the project and draft report during the meeting and on a questionnaire distributed to attendees and those unable to attend. Below are our responses to those questions and comments.

Research Methodology and Application of Results

Question: *How accurate is the TNC vernal pool mapping in the Pawcatuck River watershed? Are we concerned about possible errors of omission in areas of the Queen's watershed that we did not visit?*

Response: The TNC vernal pools database was created through stereoscopic interpretation of 1:12,000-scale, conventional, black-and-white aerial photographs taken in the spring of 1995. Of the 253 vernal pools that we studied in the Queen's, 228 (90%) were identified by TNC. We identified 11 additional pools during our fieldwork and another 14 through interpretation of digital, color ortho-photography. We and TNC may have failed to detect other pools that were either very small or hidden under a coniferous forest canopy. However, we are confident that such omissions would not have altered the location or general extent of the pool-breeding amphibian hotspots that we identified in this study.

Question: *What was the rationale behind the establishment of the specific upland forest cover classes and pool size classes for ranking purposes?*

Response: Our research and that of other scientists has demonstrated a positive relationship between the extent of upland forest cover surrounding a vernal pool and the occurrence (Homan et al. 2004), species richness (Hermann et al. 2005), and population size (Skidds et al. 2007; Egan and Paton, in press) of pool-breeding amphibians. These studies have shown that wood frog presence and abundance increase markedly when forest cover exceeds 40-50%. In creating forest cover classes for pool ranking, we attempted to differentiate among pools with low (<30% cover), moderate (30-60% cover), and high (>60% cover) suitability for breeding wood frogs. A threshold forest cover value has not been identified for spotted salamanders, but our research (Skidds et al. 2007) has shown that forest cover is positively related to egg mass counts for this species as well and that wood frog and spotted salamander egg mass counts also are positively related; therefore, the cover classes that we chose seemed reasonable for both species.

We have found a positive relationship between pool size and egg mass counts for both species also (Skidds et al. 2007). Because there was no clear threshold value for size, we simply created three classes for ranking that spanned the range of sizes encountered in the Queen's River study, with the middle class centered on the mean value (0.10 ha).

Question: *What was the rationale for recognizing a hotspot based on a minimum cluster of at least three high-ranking pools?*

Response: The three-pool minimum was not established prior to hotspot identification and it is not based on data from the scientific literature or from our previous research. It is simply based on a visual inspection of the distribution of high-ranking pools throughout the watershed, the distances among those pools, and the relative abundance of other fishless pools in the vicinity of the high-ranking pools. The minimum number of high-ranking pools in those regions where such pools were less than 1.5 km apart turned out to be three and, in our view, three was a reasonable minimum for recognition of a cluster. So the hotspots may be viewed as regions of relatively high overall pool density that are "anchored" by at least three high-ranking pools.

Question: *Why were pools 859 and 860, which are located <0.5 km from the southern boundary of Hotspot F, not included in that hotspot?*

Response: Pools 859 and 860 (see Appendix B for identification numbers) are completely surrounded by developed land (Fig. 8). As noted on page 17 of this report, we maximized the area of forested land and minimized the area of developed land during delineation of each hotspot. In this particular case, we drew the southern boundary of the hotspot along the edge between forest and developed land, so pools 859 and 860 were excluded from the hotspot.

Comment: *I suggest extending hotspot boundaries to at least 370 m beyond the pools to protect at least 95% of adult females, based on the study by McDonough and Paton (2007).*

Response: McDonough and Paton's study dealt with dispersal of adult spotted salamanders from breeding pools on a golf course where forest cover was extensive (70%), but highly fragmented, and where dispersing salamanders had to cross fairways to locate suitable terrestrial habitat. The study determined that females dispersed farther than males, that 95% of the females ended their migration within 370 m of the breeding pool, and that, on average, females dispersed more than twice as far on the golf course as at the control area, where the forest was not fragmented. Our hotspots contain the least fragmented forest tracts in the Queen's River watershed. For that reason, we felt that 300 m was a sufficient terrestrial "life zone" for the pools located at the edge of the hotspots. Pools farther from the edge have life zones far in excess of 300 m. A 300-m life zone would have captured 100% of the males and 84% of the females dispersing from pools on the golf course studied by McDonough and Paton (2007).

Question: *Are there plans to apply this methodology to other watersheds in the State?*

Response: To date, vernal pool mapping has been conducted only in the Pawcatuck River watershed, of which the Queen's is a sub-watershed. Given that our assessment methods are based on research conducted throughout the Pawcatuck, use of this methodology in other areas of the Pawcatuck would be appropriate. During the coming months, the RIDEM Office of Water Resources will be exploring the feasibility of hotspot identification in such areas using a landscape-scale approach (e.g., TNC vernal pool mapping and forest cover data from RIGIS), coupled with less intensive fieldwork. Hotspot identification outside the Pawcatuck watershed would require vernal pool mapping there and an evaluation of the appropriateness of our ranking schemes for those areas.

Question: *Are there plans to apply this methodology to vernal pools in more urbanized areas?*

Response: The pool-breeding amphibians targeted in our study are species that depend on forested habitat outside of the breeding season. For that reason, we employed the area of upland forest cover within 300 m of a pool as one of the key criteria for pool ranking. By definition, vernal pools located in urban areas have little or no forest cover around them and would represent poor habitat for species such as wood frogs, spotted salamanders, marbled salamanders, and gray treefrogs. Because our method was developed to support land conservation efforts involving both vernal pools and associated upland forests, use of the method to prioritize protection within urban landscapes would not be appropriate.

Question: *How might our findings be incorporated into local land use regulations?*

Response: Although our method was designed for non-regulatory use (i.e., to prioritize vernal pools and their surroundings for acquisition or conservation easements), the results could certainly be used to identify lands to be conserved during the planning of subdivisions or other development projects. Forested areas supporting one or more high-ranking vernal pools might be designated as one of several high-priority habitats for open space protection in a town's subdivision regulations. Other scientists (Calhoun and Klemens 2002) have identified "best development practices" that can be implemented to conserve pool-breeding amphibians during residential and commercial development throughout the northeastern United States.

Alternative Approaches to Vernal Pool Conservation

Question: *Are vernal pools protected by State wetland regulations?*

Response: Yes. Under Rhode Island's Freshwater Wetland Rules and Regulations, vernal pools may be protected as ponds (areas at least ¼-acre in size with surface water for at least 6 months); as swamps, bogs, marshes, or other types of vegetated wetlands; or as special aquatic sites (wetlands that do not satisfy the criteria for the above wetland types, but that are capable of supporting aquatic life forms of wetland-dependent wildlife such as pool-breeding amphibians). So Rhode Island's wetland regulations do regulate alteration of vernal pools, but those regulations do little to protect required upland habitats, where these amphibians live outside the breeding season, and that is a critical issue. State jurisdiction ends at the edge of special aquatic sites, and extends no more than 50 feet into the upland around ponds and vegetated wetlands. As a result, pool-breeding amphibians are highly vulnerable to human alteration of both wetland and upland habitats.

Comment: *Protection of vernal pools and pool-breeding amphibians is important, but there are many other reasons for land conservation, and we need to take a holistic approach.*

Response: We agree. Land may be conserved to protect surface water or groundwater quality and quantity, to control stream flooding, to provide public recreation areas, and to protect our natural heritage, among other reasons. We fully realize that few parcels may be preserved based on amphibian habitat value alone; however, we do think that agencies and organizations involved in land conservation should consider pool-breeding amphibians as an important group to target in their efforts to maintain the biodiversity of our landscape. Research has shown that forest preservation, in particular, is critical to the conservation of not only amphibians, but also forest-interior birds, native plant diversity, forest mammals, and other taxonomic groups. Moreover, biodiversity maintenance is clearly compatible with land conservation for the other reasons listed above.

Comment: *Recent development of decision-support model software for prioritizing land conservation is an exciting new direction that we should pursue.*

Response: We agree, and we see no reason why our scheme for prioritizing conservation of pool-breeding amphibian habitats cannot be incorporated into such models.

Comment: *Non-regulatory approaches are not the only effective means for maintaining biodiversity; local land use regulations also are important.*

Response: Again, we agree. Maintenance of our native flora, fauna, and ecosystems in the face of increasing urbanization is such a challenge that we need to employ all of the methods at our disposal—regulatory and non-regulatory—to achieve this goal. Conservation development, which has been promoted by RIDEM for some time now, can be an especially important tool at the municipal level. State and federal wetlands regulations also play an important role. Conservation land acquisition and conservation easements often are particularly effective approaches for guaranteeing protection of large, contiguous blocks of habitat—hundreds of acres or more—which are required for maintenance of pool-breeding amphibians and other area-sensitive forest wildlife.

Question: *Did we attempt to identify those factors that are most destructive to vernal pools and pool-breeding amphibians so that methods can be devised to undo the damage?*

Response: Our research over the last 10 years has focused on identifying within-pool and landscape-level habitat characteristics that positively influence the presence and abundance of pool-breeding amphibians in specific regions of watersheds so that high-quality habitat can be protected before it is damaged or lost entirely. Pool hydroperiod and the extent of upland forest surrounding breeding pools are two examples. However, it is also clear that any human actions that adversely affect these features (e.g., draining vernal pools or clearing forests in the vicinity of high-quality pools) should be regulated and even reversed, where feasible, through habitat restoration. The first step, as we saw it, was to understand the habitat requirements of the animals so that we would know which features to protect or restore.

Question: *Has RIDEM given thought to strengthening the regulations that pertain to vernal pools? Would initiation of a vernal pool certification program, such as the one in Massachusetts, be more effective for protecting vernal pools on potentially developable land?*

Response: By creating the category "special aquatic site" during the 1994 revision of Rhode Island's Freshwater Wetland Rules and Regulations, RIDEM significantly increased protection of vernal pools. Alteration of any small, seasonal body of water that is capable of supporting aquatic life forms such as fairy shrimp or pool-breeding amphibians requires a permit from RIDEM (or CRMC near the coast). In Massachusetts, such protection is not afforded until a pool has been certified (i.e., until it has been shown to support such species). Some people have questioned the effectiveness of Massachusetts' certification program because, even after more than 20 years, only a small percentage of the State's pools have been certified; meanwhile, the rest have been unprotected. In Rhode Island, protection is already in place for all vernal pools; the question of capability to support aquatic life forms is addressed when a permit application is reviewed. It would be ideal if such capability could be assessed before permit applications are filed. Conceivably, with training, local Conservation Commissions could play a role in such an effort, by documenting the value of individual pools themselves and by training landowners and other town residents to do so.

Information Needs

Comment: *More detailed information on pool-breeding amphibian hotspots (e.g., plat and lot numbers for parcels contiguous with already protected lands) would be valuable.*

Response: Plat and lot information for the 253 vernal pools included in this study is presented in Appendix C of this report, along with the location of each pool by hotspot or connecting corridor, if appropriate. We have not provided plat and lot data for upland parcels that do not contain pools (as far as we know), but RIDEM plans to compile that information in the near future and to make it available to interested parties.

Question: *Where might one obtain information on the use of aerial photographs to identify vernal pools?*

Response: We recommend the following three publications; full citations appear in the Literature Cited section of this report.

- *Vernal pools in Massachusetts: Aerial photographic identification, biological and physiographic characteristics, and State certification criteria* (Stone 1992)
- *Massachusetts aerial photo survey of potential vernal pools* (Burne 2001)
- *Best development practices: Conserving pool-breeding amphibians in residential and commercial developments in the northeastern United States* (Calhoun and Klemens 2002)
- *Remote and field identification of vernal pools* (Burne and Lathrop 2008)

Question: *Can you provide a link to natural history information on vernal pool species?*

Response: Please go to www.uri.edu/cels/nrs/paton for information on pool-breeding amphibians of Rhode Island. Other excellent sources of information on New England vernal pools are:

- *A field guide to the animals of vernal pools* (Kenney and Burne 2001)
- *Vernal pools: natural history and conservation* (Colburn 2004)
- *Science and conservation of vernal pools in northeastern North America* (Calhoun and deMaynadier 2008)

Vernal Pool Management

Question: *How would a land trust, nongovernmental organization, or government agency manage a vernal pool, if acquired?*

Response: The key is to maintain the integrity of the pool and to maintain forested habitat up to a distance of several hundred meters around the pool, if possible. The pool should be protected from polluted surface runoff (including sedimentation) and polluted groundwater inflow, from hydrologic modification (e.g., impoundment or ditching), and from clearing of vegetation in the pool or in the surrounding upland. We highly recommend the excellent publication on "Best Development Practices" by Calhoun and Klemens (2002) for a detailed treatment of alterations to avoid and BMPs to employ. Restoration is recommended for pools that have been severely degraded as a result of human activity.

Question: *Would it be possible to raise the spillway of lower-ranking pools in order to lengthen the hydroperiod and make them more valuable?*

Response: Some vernal pools have surface outlets; others do not. If a pool has a surface outlet, it might be possible to lengthen the hydroperiod by raising the elevation of the outlet; however, we would not recommend manipulating the hydroperiod, or any other characteristic, of an undisturbed vernal pool to make it "more valuable." Our ranking of pools in the Queen's River watershed according to size, hydroperiod class, and extent of surrounding forest was done simply to identify those pools and watershed regions that are potentially capable of supporting unusually high numbers or diversity of pool-breeding amphibians for non-regulatory protection, realizing that funds are limited and prioritization is necessary. However, even pools with short hydroperiods may provide excellent habitat for certain aquatic invertebrates and certain amphibians and may support multiple species in wetter than average years. Our recommendation would be to maintain, in any geographic area, pools with diverse hydroperiods so that adequate breeding habitat would be available in at least some ponds regardless of annual precipitation levels (see Semlitsch [2000] for further discussion of this topic). We recommend pool manipulation only if the goal is to restore the wetland to a previous, undisturbed condition, and then only if the required permits have been obtained.

Question: *What procedures or permits would be required for creation or restoration of vernal pools?*

Response: If the goal is to create a vernal pool from upland, and the site does not lie within "riverbank wetland" (i.e., within 100 feet of a stream less than 10 feet wide or within 200 feet of a stream at least 10 feet wide) or "perimeter wetland" (i.e., within 50 feet of the edge of any bog, marsh, swamp, or pond as defined in the RI Freshwater Wetlands Act), then a wetland permit is not required. If one wishes to restore a degraded vernal pool or to create one within existing wetland, such as a swamp, a permit must be obtained from RIDEM (or CRMC in the vicinity of the coast). RIDEM recommends that applicants for such permits contact the RIDEM Wetland Restoration Team for guidance prior to filing an application.

Question: *Has Rhode Island (presumably RIDEM) established a minimum percentage of vernal pools for restoration?*

Response: We are aware of no past or current efforts to restore degraded vernal pools in this state, nor do we know of any plans for future restoration of individual pools or pools on a landscape scale. Before a landscape-level vernal pool restoration plan could be developed, there must be a comprehensive inventory (including field-checks) of both disturbed and undisturbed pools. In Rhode Island, the TNC inventory of potential vernal pools in the Pawcatuck River watershed is the only comprehensive inventory available. That inventory was conducted through interpretation of aerial photographs; probably less than 20% of those potential vernal pools have been verified in the field. Clearly, vernal pool restoration goals cannot be set without more data on the location and condition of existing and former pools.

Related Topics

Comment: *The State's Land Use Plan for 2025 targets certain areas for development; vernal pool information is needed for those areas and for areas targeted for water supply.*

Response: To develop effective management plans for the conservation of vernal pools and their fauna, we need to identify and assess the habitat quality of vernal pools across the Rhode Island landscape—in areas targeted for development and in areas that are still rural and, ideally, contiguous with protected land. Our study sought to identify pool-breeding amphibian hotspots that could serve as focal points for a comprehensive management plan in the Queen's River watershed. We believe that this approach is applicable throughout the State.

Question: *How might landowners be brought into the vernal pool protection process?*

Response: Vernal pool owners are uniquely positioned to impact the health of these habitats and their fauna, both positively and negatively. Grassroots efforts by municipal Conservation Commissions, watershed associations, land trusts, and other nongovernmental conservation organizations might be the most effective in educating landowners about the values of vernal pools, ways to minimize adverse impacts, means for enhancing their value, and the benefits of various land protection methods. Agencies such as RIDEM, CRMC, and the Natural Resources Conservation Service (NRCS) might provide training for these local groups and serve as a continuing source of information and technical assistance. NRCS also may be able to provide funds to landowners for vernal pool creation, enhancement, or restoration.

Question: *Does RIDEM consider vernal pool protection when ranking applications for funding under the State's Open Space grants program?*

Response: Open Space grant applications are ranked out of a total of 100 points based on point values assigned to several different scoring criteria. Habitat protection criteria (up to 25 points total) are further divided into five sub-categories (up to 5 points each). The first of those sub-categories is critical and/or uncommon habitat and vernal pools are listed as one of the habitat/community types considered. A parcel containing vernal pools may have additional points awarded for other habitat protection criteria such as rare/endangered species. The specific characteristics of the parcel may result in points awarded for other criteria in addition to habitat protection. Information on the Local Grants Program can be found on the RIDEM Office of Planning and Development webpage: http://www.dem.ri.gov/programs/bpoladm/plandev/grants.htm