

HABITAT PROFILE

Vernal Pools

Associated Species: Marbled Salamander, Jefferson Salamander, Blue-Spotted Salamander, Spotted Turtle, Blanding's Turtle, Ribbon Snake
Global Rank: Not ranked
State Rank: Vernal woodland pool (S3), vernal floodplain pool (S2)
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ELEMENT 1: DISTRIBUTION AND HABITAT

1.1 Habitat Description

Vernal pools are depressional wetlands characterized by generally small size, physical isolation, and alternating periods of flooding and drying. Precipitation and groundwater levels determine hydroperiod, though some are fed by spillover from nearby water bodies or intermittent streams. Vernal pools with a hydroperiod shorter than two months (in spring or summer) may be more properly characterized as ephemeral, as they are not inundated long enough for vernal pool species to complete their life cycle (Colburn 2004). Pools inundated less than four months following spring ice-out might not support a full array of vernal-pool dependent amphibians (Paton and Couch 2002, Babbitt et al. 2003).

The regular drying of vernal pools prevents fish from becoming established. Larvae of vernal pool amphibians lack (or have weakly developed) anti-predator mechanisms to cope with fish predation (Wellborn et al. 1996, Skelly 1997). Technically, vernal pools are hydrologically isolated from other water bodies; however, sites that form periodic connections with other bodies, or that do not dry every year can support vernal pool species if fish populations do not become established.

Vernal pools often have little vegetation. However, pools with a long hydroperiod often have a variety

of wetland plants such as *Sphagnum*, sedges, rushes, ferns, shrubs, and trees. Common shrubs and trees in vernal pool depressions include buttonbush (*Cephalanthus occidentalis*), highbush blueberry (*Vaccinium corymbosum*), winterberry (*Ilex verticillata*), red maple (*Acer rubrum*), speckled alder (*Alnus rugosa*), and eastern hemlock (*Tsuga canadensis*) (Colburn 2004, Sperduto and Nichols 2004).

1.2 Justification

Concern for vernal pool conservation is that they are small and easily overlooked (because they are seasonally dry), thus more likely to be filled during development. Because they are temporary, they historically received weaker regulatory oversight than larger permanent wetlands. Increasing population growth in the state and associated development will result in loss of vernal pools and disruption of dispersal capabilities (via increased roads and road traffic) of species that rely on them. Significant loss of vernal pool habitat can result in local extirpation of obligate vernal pool species such as the fairy shrimp (*Eubranchipus* spp.), wood frog (*Rana sylvatica*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*), Jefferson salamander (*Ambystoma jeffersonianum*), and the state endangered marbled salamander (*Ambystoma opacum*). In addition, other species of concern such as the Blanding's turtle (*Emydoidea blandingii*) and spotted turtle (*Clemmys guttata*) feed in vernal pools and use them as staging areas during migration (Joyal et al. 2001, Jenkins and Babbitt 2003).

1.3 PROTECTION AND REGULATORY STATUS

Vernal pools do not have any special regulatory protection at the state level. Local wetland regulations and zoning vary considerably. Some towns (e.g.,

Litchfield) have initiated upland buffer protection around vernal pools. Because vernal pools are generally small and regulatory review of wetland impacts often focuses on size of impacts, vernal pools could be overlooked (M. Marchand, NHFG, personal communication). The NHDES Wetlands Bureau does not require construction setbacks from non-tidal freshwater wetlands (except under RSA 485-A).

- State Fill and Dredge in Wetlands; NHDES, RSA 482-A: Requires applicant to obtain a permit to fill or dredge jurisdictional wetland habitats. Although vernal pools should be identified as jurisdictional wetlands, they will not necessarily be identified as breeding habitat for obligate vernal pool amphibians and invertebrates.
- Nongame Species Management Act (1988) (RSA 212-B): The NHFG Nongame and Endangered Species Program has responsibility and authority to conduct research, management, and education related to those species not hunted, fished, or trapped.

1.4 Population and Habitat Distribution

Vernal pools are widespread throughout New Hampshire and the Northeast, but generally are less abundant in mountainous regions. Because vernal pools are under-reported on National Wetland Inventory (NWI) maps, the location and abundance of vernal pools in New Hampshire are not known. Further, historical records of vernal pool distribution and abundance are lacking. Vernal pools have been identified in areas of New Hampshire for various purposes including research (e.g., Turtle 2000, Jenkins and Babbitt 2003, Mattfeldt 2004, Hermann et al. 2005, Tarr et al. In Press), natural resource inventories, and citizens documenting vernal pools using the Identification and Documentation of Vernal Pools in New Hampshire manual (Tappan and Marchand 2004). However, these data have not been compiled into one database.

1.5 Town Distribution Map

See attached.

1.6 Habitat Map

1.7 Sources of Information

Sources of information include a literature review, the NHDES website, and NHFG.

1.8 Extent and Quality of Data

Vernal pool habitat is well documented in the scientific literature. Specific knowledge about the distribution and abundance of vernal pools in different areas of the state is lacking and is needed.

1.9 Distribution Research

There is a critical need to map vernal pools in New Hampshire and create a database (including GIS data layers) to store data for documented vernal pools. Information on vernal pool spatial distribution, density, hydroperiod, and breeding suitability for vernal pool obligates should also be collected.

ELEMENT 2: SPECIES/HABITAT CONDITION

There is a general lack of data relevant to section 2. Knowledge about the distribution of vernal pools in the state is lacking and is needed. No assessment of quality of vernal pool habitats has been conducted.

The relative health of vernal pools is closely tied to the quality of surrounding upland habitat. Hydroperiod and land use strongly influence the suitability of vernal pools for pool-dependent wildlife (Semlitsch 2000, Snodgrass et al. 2000, Paton and Couch 2002, Babbitt et al. 2003, Mattfeldt 2004, Hermann et al. 2005, Babbitt in press). It would be instructive to develop a bioassessment program for vernal pools that is stratified by relevant spatial scale (e.g., country, bioregion) and land use (e.g., urban, suburban, forested, agriculture, protected). Measures of health or quality could include measures of amphibian use (e.g., species richness of vernal-pool dependent species, amphibian egg mass counts), species richness/abundance of aquatic insect taxa, standard water quality measures (e.g., pH, conductivity, nitrogen, phosphorus, BOD, temperature, DOC), and contaminants. Presence of fish or invasive species should be documented. Wetland hydroperiod should be measured, and the bioassessment program must be

developed with a critical examination of land use and land use change attributes.

ELEMENT 3 HABITAT THREAT ASSESSMENT

3.1.1 Development (Habitat Loss and Conversion)

(A) Exposure Pathway

Development may affect breeding habitat (loss and degradation of vernal pools), upland habitat (loss and degradation of forests), and dispersal corridors (by fragmenting landscapes), and may even directly kill vernal pool wildlife (vehicle traffic, land clearing activity, etc). Runoff from roads and other impervious surfaces can pollute and degrade nearby wetland habitat. Opportunistic predators (e.g., raccoons) and invasive plant and animal species are more common near human development. Myriad stressors associated with development collectively reduce local population sizes of amphibians, reduce gene flow between populations, and may ultimately extirpate local populations.

(B) Evidence

The evidence provided below is focused on amphibians. Vernal pools often occur in discrete patches within a matrix of terrestrial habitat, and amphibians that breed in these habitats may exist as metapopulations (e.g., Gill 1978, Sjögren 1991, Sinsch 1992, Marsh and Trenham 2001). The long-term persistence of populations depends on the exchange of individuals through dispersal and the colonization probability of vernal pools from terrestrial adult populations (Hanski and Gilpin 1991, Sjögren, 1991, Dodd 1997, Semlitsch and Bodie 1998, Skelly et al. 1999). Most amphibians use terrestrial habitat to obtain food and shelter from predation, desiccation, or freezing (Madison 1997, Lamoureux and Madison 1999, Knutson et al. 1999). Therefore, the suitability of terrestrial habitat surrounding a vernal pool is likely to have a significant influence the composition and abundance of amphibians that breed in or otherwise utilize a vernal pool.

Even strict wetland regulations and oversight may not protect vernal pool habitat suitability if upland habitat is not also protected. Maintenance of appropriate terrestrial habitat, through buffers (e.g., Semlitsch 1998, Calhoun and deMaynadier 2001,

Calhoun and Klemens 2002, Semlitsch and Bodie 2003) or other means will offer some protection, although more research is needed determine both the utility and consequences of guiding development or logging practices via this mechanism. Further, because some species range widely (e.g., Blanding's turtle), a landscape-level approach to conservation and planning will be required to ensure long term persistence of the full range of species associated with vernal pools.

In the last few decades, commercial and residential development in New Hampshire have increased dramatically, in conjunction with accelerated human population growth and immigration (Sundquist and Stevens 1999). Similar urbanization has eliminated the marbled salamander from large portions of its former range on Long Island and mainland New York (Klemens 1993). Petranka (1998) noted that thousands of local populations of marbled salamanders have already been eliminated due to habitat loss. Windmiller (1996) noted that increasing urbanization likely reduces mole salamander abundance and excludes salamanders from otherwise suitable habitat. Gibbs (1998a) suggested that ambystomatids are predisposed to local extinction caused by habitat fragmentation.

3.1.2 Transportation Infrastructure (Mortality, Fragmentation, Dispersal Barriers)

(A) Exposure Pathway

Vehicle traffic can kill vernal pool-dependent species by hitting and crushing them as they cross roads. This can have a significant impact on some species, particularly rare turtles, and in severe cases could result in local extirpation. Roads may act as partial barriers to overland dispersal or migration, perhaps resulting in decreased gene flow between populations and decreased colonization of unpopulated vernal pools. This could disrupt metapopulation dynamics and long-term viability of some species.

Roads also create edge habitat. Along these edges, soil and air moisture may be reduced, leading to increased salamander desiccation. Roads may act as conduits for predators that prey on amphibians or turtle eggs (e.g., skunks and raccoons), and dispersal avenues for invasive plants and animals. Runoff from roads can also reduce habitat quality of vernal pools via pollution, increased salt levels, sedimentation, and erosion in pools and adjacent habitats.

(B) Evidence

Roads significantly threaten turtles, causing skewed sex and age ratios (Marchand and Litvaitis 2004, Gibbs and Steen 2005). Computer modeling by Gibbs and Shriver (2002) predicted that relatively low road densities (e.g., 1 km/km² with > 100 vehicles/lane/day) could result in severe negative impacts on semi-terrestrial turtles. Roads are a significant source of direct mortality for migrating amphibians (Fahrig et al. 1995, Ashley and Robinson 1996, Mazerolle 2004, Forman 2003), and salamander abundance in roadside habitats may be reduced (deMaynadier and Hunter 2000). Gibbs (1998) found that forest-road edges are less permeable to ambystomatid salamanders than are forest interior and forest-open land edges. Recent research conducted in southern New Hampshire suggests that roads have a negative impact on wood frogs (*Rana sylvatica*) and spotted salamanders (*Ambystoma maculatum*), two species of amphibians that breed in vernal pools (Mattfeldt 2004). Amphibians can experience delayed development or mortality from runoff contamination from roads, including road salt (Trombulak and Frissell 2000, Turtle 2000). Negative effects of roads have been well documented for a variety of animal and plant species, and likely apply generally to vernal-pool dependent species (Vos and Chardon 1998, Forman and Deblinger 2000, Carr and Fahrig 2001, Forman 2003, Mazerolle 2004).

3.1.3 Development (Habitat Loss and Conversion)**(A) Exposure Pathway**

Vernal pools are filled to provide non-wet areas for residential and commercial development, recreation, agriculture, and road development. Vernal pool filling results in immediate loss of habitat and, for certain species, population extirpation. Wetland filling also increases the distance that dispersing amphibians must travel to reach suitable breeding habitat, resulting in decreased gene flow between local populations and decreased colonization of unpopulated breeding pools. This could disrupt metapopulation dynamics and long-term viability of the species.

(B) Evidence

Wetland loss in the United States from historic draining and filling is well documented (e.g., Dahl 1990,

2000); see Marsh and Shrub Wetlands profile for details. Lack of reliable data for vernal pools creates difficulty in accurately determining historic losses. An important aspect of wetland loss is not simply the continued loss of habitat, but the continued undervaluing of vernal pool habitat as well. Size has traditionally been used an important criterion for assessing wetland value. Further, recent Supreme Court ruling (SWANCC 2001) decreases protection for wetlands that are “isolated” from waters of the United States, under the federal regulation of dredge and fill as per Section 404 of the Clean Water Act. Although the consequences of this decision are still being debated, it likely results in no federal protection under Section 404 for most or all vernal pools. Thus, it falls to the state or local governments to ensure that vernal pools are protected (see section 1.3). New Hampshire has the fastest growing population in New England (Sundquist and Stevens 1999) and consequently faces significant development impacts. Without increased protection priority for vernal pools, it is certain that vernal pool habitat will decrease in the future.

Amphibians, particularly ambystomatid salamanders, generally breed in the same wetland every year (Semlitsch et al. 1993, Semlitsch 1998). It is not well known how these species respond when a breeding wetland is no longer available (i.e., filled). Some ambystomatid salamanders will return to breeding wetlands even after those wetlands have been filled, whereas others have been able to disperse to nearby created wetlands (Pechmann et al. 2001). Created mitigation wetlands usually are unsuccessful at replicating the functional or wildlife habitat of the wetlands they are intended to replace (Brown 1999).

3.1.4 Unsustainable Harvest (Forestry Operations and Management)**(A) Exposure Pathway**

Forest management practices such as clear cutting and partial cutting.

(B) Evidence

Forest management practices (e.g., clear cutting, partial cutting) may reduce forest canopy cover over or near vernal pools. This often results in warmer ambient temperatures (in soil, water, and air), increased wind, and increased insolation. Higher temperatures and wind can lead to increased desiccation and mor-

tality of dispersing or breeding amphibians. Higher temperatures may increase metabolism, increasing energetic demands and leading to starvation if food is scarce. Greater irradiation of breeding wetlands may increase water temperatures, wetland hydroperiod, and exposure to UV radiation.

Forest cutting might disrupt dispersal corridors, force species into suboptimal habitat, and increase exposure to predation or competition. Logging roads can be barriers to wildlife movement, or alternatively, create areas that attract breeding amphibians but that dry too quickly or are subject to vehicular traffic. Runoff from logging roads can transport silt and other pollutants to breeding wetlands, interfering with breeding, embryonic development, and juvenile survival. Reforestation of commercial forests solely with evergreen species [e.g., red spruce (*Picea rubens*)] is not optimal for species that prefer deciduous/mixed upland areas.

3.2 Sources of Information

Information was obtained from a literature search.

3.3 Extent and Quality of Data

The quality of existing data is relatively good in terms of our general understanding of factors that are likely to impact vernal pools and associated fauna. However, we lack information on the abundance and distribution of vernal pools in the landscape in New Hampshire. Further, to be able to make informed decisions about vernal pool protection, we need better data on the terrestrial habitat requirements of obligate (and facultative) users of vernal pools.

3.4 Threat Assessment Research

An accurate map of vernal pools is needed for the state. Because not all vernal pools show up on NWI maps, this is not a trivial task. Wetland filling, as a threat, is driven by developmental pressure and how the state of New Hampshire chooses to regulate wetland filling. NHDES maintains records of legal filling activities and could use a comparative aerial photography approach (i.e., before-after) to document recent (e.g., last 10 years) illegal impacts to vernal pools. Monitoring of vernal pool habitat quality (e.g., water quality, hydroperiod) must be conducted concurrently with

research that examines land use attributes (e.g., land use type, roads, impervious surface, etc.) on vernal pool habitat quality and ability to support species dependent on vernal pools.

ELEMENT 4: CONSERVATION ACTIONS

This list is not intended to be exhaustive (particularly 4.1.2 – 4.1.13), but rather to provide a list of conservation actions that should have the greatest conservation impact or that are needed to enhance threat assessment activities.

4.1.1 Rewrite Municipal Zoning Codes, Habitat Protection/Regulation and Policy

(A) Development, roads, wetland fill, pollution (toxins, fertilizers, increased soil and water acidity), disease, invasive species, fish stocking, collection, global warming.

(B) Justification

Rewriting local zoning codes to favor open-space and mixed-use development is expected to be the most effective means of reducing the negative effects of development and thereby protecting vernal pool habitat and pool-dependent wildlife. Rewriting local zoning codes should have the following effects, compared to development under conventional zoning codes:

- Development can be clustered more densely, allowing permanent preservation of and connection between larger tracts of undeveloped land, and reduced fragmentation of the landscape.
- Transportation infrastructure can be reduced, since buildings are closer together; and residential, commercial, and industrial buildings are intermixed. Consequently, effects of roads and development (see sections 3.1.1 and 3.1.2) on vernal pools and their wildlife can also be reduced.
- The design process is more flexible so that development can be planned around, instead of through or near, vernal pools, wildlife migration routes, and other valuable natural resources.

This action can be applied at the state or municipal level. This action is most critical in those areas experiencing the greatest population growth (i.e., southern and southeastern New Hampshire). Revised zoning

codes can be implemented quickly if supported by the public. Model zoning codes already exist and can be adapted to local situations. Moreover, state law (i.e., NH RSA 674, RSA 675, RSA 477) already permits municipalities to amend zoning codes such that they allow or promote open-space and mixed use development. Zoning codes can be revised as needed to respond to new information.

(C) Conservation Performance Objective

The objective of rewriting zoning codes is to promote and facilitate open-space/mixed use development, instead of traditional (low-density, large-lot, separated land use) development. Zoning codes should be revised as soon as feasible, and the effect on open-space/mixed use development should be documented within a year of implementation.

(D) Performance Monitoring

Performance will be assessed using the following three parameters:

1. Number of towns that have adopted revised zoning codes (that favor open-space/mixed use development)
2. Numbers of each type of building permit (open-space/mixed use versus conventional)
3. Acreage claimed by each type of development (for all developments, this includes land that is part of the developable parcel but not developed, such as permanently-preserved open space in open-space developments)

These parameters should be measured on a regular basis at the municipal level and will be reported to the agency that is charged with monitoring this conservation action. The municipal scale is most practical since municipal boards will possess this information because of municipal zoning (planning) board activities and the development permitting process. If performance is deemed unsatisfactory, the entity charged with administering this conservation action should consider methods to promote this action, including educating municipal zoning boards and the public.

(E) Ecological Response Objective

The desired ecological results of revising zoning codes are to maintain large mosaics of relatively undisturbed forest and wetland habitats. This habitat-based approach should allow local wildlife populations to persist.

(F) Response Monitoring:

Several ecological responses could be monitored, depending on research or management goals. The following list provides a few examples:

- Survey the distribution and abundance of target vernal pool wildlife (salamanders, turtles)
- Monitor breeding habitat (habitat structure, water chemistry, pollution, etc)
- Monitor populations for growth, mortality, fecundity, migration, and occurrence of disease or deformities
- GIS data layers for vernal pools and target wildlife species should be developed using aerial photographs and/or remote sensing data. Separate data layers could be developed for other measured habitat or population variables
- Develop indicators for breeding habitats (hydroperiod, landscape position, etc), upland landscapes (forest area, forest to edge ratio, and landscape connectivity), and human development (road density, impervious surfaces, etc.)
- Add a zoning code status layer to the GIS map. Then periodically update field and aerial/remote sensing data to compare indicators (above) over time to evaluate the effects of zoning changes (or compared with models).
- If response indicators show that vernal pool habitat or critical upland habitat continues to degraded or fragmented, or vernal pool wildlife are decreasing, then this conservation action should be read-dressed.

(G) Implementation

Educate the public, municipal zoning boards, and real estate agents about the benefits of open-space/mixed-use development. Develop a model open-space/mixed use zoning code for each municipality and have it endorsed by the municipal zoning board, town meeting, or otherwise have it approved as outlined in NH RSA 91, RSA 477, RSA 674, and RSA 675). A state agency, consulting group, or non-profit group should coordinate a statewide effort, although towns may also want to delegate responsibilities to volunteers, zoning board or conservation commissioners, or consultants. Efforts should first focus on communities where critical species are known to exist. For example, Winchester is the only municipality where a pure Jefferson salamander has been documented and should

therefore receive special attention.

Incorporate data from habitat surveys, rare species surveys, and GIS datalayers (see section 4.1.1 F) into proposed zoning codes and to revise codes as new information becomes available. Calculate ecological response indicators to assess the success of the conservation action.

4.1.2 Maintain the natural hydroperiod of individual vernal pools. Regulations should not allow for dredging, excavation, drainage, or filling in or adjacent to vernal pools. (Habitat Protection/Regulation and Policy)

Any changes to wetland hydroperiod can alter habitat suitability, including rendering the pool unsuitable for supporting many vernal pool-dependent species. Vernal pools in which hydroperiods are shortened may not be inundated for a sufficient length of time to allow development of larval amphibians to metamorphosis. Vernal pools that are converted to permanent sites will not support the same assemblage of species if fish populations become established.

4.1.3 Change wetland dredge and fill and set back regulations so that vernal pools are given equal value to other wetland types. When vernal pools are impacted or completely filled in, compensatory mitigation should be required. Use wetlands functions and values assessments when evaluating permit applications, rather than focusing on size of wetland impact (Habitat Protection/Regulation and Policy).

The continued approach of placing higher value on larger wetlands will result in relatively higher loss of vernal pool habitat compared to other wetlands because a large majority of vernal pools are small. There is ample evidence that size is a poor criterion on which to measure wetland value (Gibbs 1993, Semlitsch and Bodie 1998, Snodgrass et al. 2000, Paton and Couch 2002, Babbitt in press).

4.1.4 Establish a mechanism to use mitigation funds for wetland loss to support efforts to conduct applied research on impacts of development and on vernal pools. (Regulation and Policy/Habitat Protection)

As measures are taken to encourage “smart growth” and establish Best Management Practices (BMPs) for vernal pools, it is important to examine whether these approaches are effective. Long-term research would be required, so commitment on the part of developers at the start of development projects would be necessary. Although this conservation action would require significant time and effort, it is an effective and direct way of obtaining critically needed information about how best to manage land in a developed landscape. Given trends in population growth and development, the suburban landscape is the area in which impacts to vernal pools and the species that depend on them is likely to offer both the greatest challenges and the greatest opportunities for conservation.

4.1.5 Establish a GIS data layer for vernal pools. (Habitat Protection)

An accurate map of vernal pools is needed to efficiently and effectively conserve vernal pools, track impacts, assess protection efforts, assess threats, and to document and seek mitigation for legal and illegal filling.

4.1.6 Create a database to store the location and condition of documented vernal pools (Habitat Protection, Regulation and Policy, Education and Outreach)

NHFG published a guide ‘Identification and Documentation of Vernal Pools in New Hampshire’ (Tappan and Marchand 2004). Landowners, citizens, towns, consultants, and non-profits have used this manual to document vernal pools in New Hampshire and submitted documentation to NHFG. In addition, many vernal pools have been documented and studied as part of research conducted by schools and universities, especially the University of New Hampshire (e.g., Turtle 2000, Jenkins and Babbitt 2003, Mattfeldt 2004, Hermann et al. 2005, Tarr et al. In Press). All documented vernal pools should be acquired and stored in a central database. This information could be used during development site reviews, prioritizing land for protection, creating species habitat models, or identifying locations for research.

4.1.7 Determine location of vernal pool-rich areas of the landscape and permanently protect the land. (Habitat Protection)

The most permanent source of protection for vernal pools and vernal-pool dependent species is through land protection that includes wetlands and critical uplands. Land protection through fee simple purchase or easements should be considered.

4.1.8 Support establishment of BMPs for vernal pools. (Habitat Protection/Regulation and Policy)

Vernal pool BMPs have recently been developed for residential and commercial development (Calhoun and Klemens 2002) and forestry (Calhoun and deMaynadier 2001). These BMPs are laudable and provide a good first step. However, research to test the efficacy of these BMPs is lacking. It is unclear whether these BMPs, which largely establish terrestrial buffer zones, will result in long-term protection of widely ranging species. Support of BMPs for vernal pools, together with research to examine their utility and need for refinement, should be established.

4.1.9 Support development design standards that keep roads distant from vernal pools and that limit use of road salt in areas where vernal pools are adjacent to roads. (Habitat Protection)

See section 3.1.2 for justification. To the extent possible, roads should not be constructed to run near a vernal pool, through a cluster of vernal pools, or between vernal pools and forested uplands. Alternatives to standard road salt applications should be used on roads adjacent to vernal pools.

4.1.10 Establish standards for the development of criteria for assessing and determining critical locations for tunnel crossings. (Habitat Protection)

The use of tunnels to safely direct wildlife under or over roads has proven effective in many circumstances, including for vernal pool species. Care must be taken to design structures that animals will use (i.e., no behavioral avoidance) and are not likely to experience increased predation (i.e., from predators

cuing in on migrating organisms). Tunnel crossings are particularly important in areas where rare, endangered, threatened, or species of special concern still occur (e.g., marbled salamander, Jefferson salamander, Blanding's turtle, spotted turtle). For more details see Jefferson salamander profile.

4.1.11 As part of broader initiative relative to invasive species management, document trends in increasing invasive species in vernal pools. (Habitat Management)

Invasive species are not considered a significant threat to vernal pools now, but should be watched to ensure that this threat does not increase in the future.

4.1.12 Recognize that the spatial relationship among pools of varying hydroperiod, including permanent sites, has a significant influence on local biodiversity. (Habitat Protection)

Efforts should be undertaken to develop watershed-scale conservation management plans. Because we lack historic data on vernal pool abundance, we do not know what we have lost. However, maintaining a similar ratio of wetlands in differing hydroperiod/habitat types, as well as maintaining uplands surrounding these wetlands in a fashion that will support wetland-dependent species, will ensure that the relative densities of vernal pools are not decreased significantly relative to other habitat types. For example, species such as the Blanding's turtle require both permanent pools and vernal pools.

4.1.13 Develop a bioassessment program for vernal pools.

A suitable approach for assessing vernal pool quality is lacking. Because it is not likely that development will abate or that all vernal pools will be protected, it will become increasingly important to assess the value of vernal pools to decrease our chances of "protecting the wrong pools." A bioassessment program should be stratified by relevant spatial scale (e.g., country, bio-region) and land use (e.g. urban, suburban, forested, agriculture, protected). Measures of health or quality could include measures of amphibian use (e.g., richness of vernal-pool dependent species, amphibian egg mass counts) species richness/abundance of aquatic

insect taxa, standard water quality measures (e.g., pH, conductivity, nitrogen, phosphorus, BOD, temperature, DOC), and contaminant levels. Presence of fish or invasive species should be documented. Wetland hydroperiod should be measured, and the bioassessment program must be developed with a critical examination of land use and land use change attributes that can be obtained through remote sensing (e.g., Tiner 2004).

4.2 Conservation Action Research

In addition to the need for documentation and mapping of vernal pools, it is essential to assess what protection and management activities in the terrestrial landscape will ensure that vernal pools retain habitat quality and continue to support wildlife. Information needs include species-specific requirements, and the quality, amount, and type of habitat required for long-term maintenance of populations. More research on dispersal mechanisms and upland habitat is needed to protect some pool-dependent species.

ELEMENT 5: REFERENCES

- Ashley, E.P., and J.T. Robinson. 1996. Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario. *Canadian Field-Naturalist* 110: 403-412.
- Babbitt, K.J., M.J. Baber, and T.L. Tarr. 2003. Patterns of larval amphibian distribution along a wetlands hydroperiod gradient. *Canadian Journal of Zoology* 81:1539-1552.
- Babbitt, K.J. in press. The relative importance of wetland size and hydroperiod for amphibians in the northeast. *Wetland Ecology and Management*.
- Calhoun, A.J.K., and P. deMaynadier. 2001. Forest habitat management guidelines for vernal pool wildlife in Maine. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.
- Calhoun, A.J.K., and M.W. Klemens. 2002. Best management practices: conserving pond-breeding amphibians in residential and commercial developments in the northeastern United States. MCA Technical Paper No. 5. Metropolitan Conservation Alliance, Wildlife Conservation Society. Bronx, New York.
- Carr, L.W., and L. Fahrig. 2001. Effects of road traffic on two amphibian species of differing vagility. *Conservation Biology* 15:1071-1078.
- Colburn, E.A. 2004. Vernal pools: natural history and conservation. McNaughton & Gunn, Inc. Saseline, Michigan.
- Dahl, T.E. 1990. Wetlands losses in the United States 1780s to 1980s. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.
- Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997 U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.
- deMaynadier, P.G., and M.L. Hunter, Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. *Environmental Reviews* 3:230-261.
- deMaynadier, P.G., and M.L. Hunter. 2000. Road effects on amphibian movements in a forested landscape. *Natural Areas Journal* 20:56-65.
- Dodd, C.K., Jr. 1997. Imperiled amphibians: a historical perspective. Pages 165 – 200 in G. W. Benz and D. E. Collins, editors. *Aquatic Fauna in peril: the southeastern perspective*. Special Publication I Southeast Aquatic Research Institute. Lenz Design and Communications, Decatur, Georgia, USA.
- Fahrig, L., J.H. Pedlar, S.E. Pope, P.D. Taylor, and J.F. Wegner. 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73:177-182.
- Forman, R.T.T. 2003. *Road ecology: science and solutions*. Island Press. Washington, D.C.
- Forman, R.T.T., and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. *Conservation Biology* 14:36-46.
- Gibbs, J.P. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. *Wetlands* 13:25-31.
- Gibbs, J.P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in southern New England. *Journal of Wildlife Management* 62: 584-589.
- Gibbs, J.P., and D.A. Steen. 2005. Trends in sex ratios of turtles in the United States: implications of road mortality. *Conservation Biology* 19:552-556.
- Gibbs, J.P., and G. Shriver. 2002. Estimating the Effects of Road Mortality on Turtle Populations. *Conservation Biology* 16:1647-1651.
- Gill, D.E. 1978. The metapopulation ecology of the red-spotted newt, *Notopthalmus viridescens* (Rafin-

- esque). Ecological Monographs 48:145-166.
- Guerry A.D. and Hunter M.L., Jr. 2002. Amphibian distributions in a landscape of forests and agriculture: an examination of landscape composition and configuration. Conservation Biology 16:745-754.
- Hanski, I. 1994. Patch-occupancy dynamics in fragmented landscapes. Trends in Ecology and Evolution 9:131-135.
- Hanski, I., and M.E. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnean Society 42:3-16.
- Hecnar, S.J., and R.T. M'Closky. 1996. Regional dynamics and the status of amphibians. Ecology 77: 2091-2097.
- Hermann, H.L., K.J. Babbitt, M.J. Baber, and R.G. Congalton. 2005. Effects of wetland and surrounding landscape characteristics on amphibian assemblages. Biological Conservation. 123:139-149.
- Jenkins, R., and K.J. Babbitt. 2003. Developing a conservation strategy to protect land habitat functions for New Hampshire's reptiles and amphibians using the Blanding's turtle (*Emydoidea blandingii*) as a flagship species. Final report submitted to the New Hampshire Fish & Game Department, Concord, New Hampshire, USA.
- Joyal, L.A., M. McCollough, and M.L. Hunter, Jr. 2001. Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. Conservation Biology 15: 1755-1762.
- Knutson, M.G., J.R. Sauer, D.A. Olsen, M.J. Mossman, L.M. Hemesath, and M.J. Lannoo. 1999. Effects of landscape composition and wetland fragmentation on Frog and Toad abundance and species richness in Iowa and Wisconsin, USA. Conservation Biology 13: 1437-1446.
- Laan, R. and B. Verboom. 1990. Effects of pool size and isolation on amphibian communities. Biological Conservation 54:251-262.
- Lamoureux, V.S., and D.M. Madison. 1999. Overwintering habitats of radio-implanted green frogs, *Rana clamitans*. Journal of Herpetology 33:430-435.
- Lehtinen, R.M., S.M. Galatowitsch, and J.R. Tester. 1999. Consequences of habitat loss and fragmentation for wetland amphibian assemblages. Wetlands 19:1-12.
- Madison, D.M. 1997. The emigration of radio-implanted spotted salamanders, *Ambystoma maculatum*. Journal of Herpetology 31:542-551.
- Marchand, M.N., and J.A. Litvaitis. 2004. Effects of habitat features and landscape composition on the population structure of a common aquatic turtle in a region undergoing rapid development. Conservation Biology 18:758-767.
- Marsh, D.M. and P.B. Pearman. 1997. Effects of habitat fragmentation on the abundance of two species of Leptodactylid frogs in an Andean montane forest. Conservation Biology 11:1323-1328.
- Marsh, D.M., and P.C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology 15:40-49.
- Mattfeldt, S. 2004. Effects of wetland isolation and surrounding landscape characteristics on vernal pool-dependent amphibians. M.S. Thesis. University of New Hampshire, Durham, New Hampshire.
- Mazerolle, M.J. 2004. Amphibian road mortality in response to nightly variations in traffic intensity. Herpetologica 60: 45-53.
- Paton, P.W.C., and W.B. Couch, III. 2002. Using phenology of pond-breeding amphibians to develop conservation strategies. Conservation Biology 16: 194-204.
- Pope S.E., L. Fahrig, and H.G. Merriam. 2000. Landscape complementation and metapopulation effects on leopard frog populations. Ecology 81: 2498-2508.
- Semlitsch, R.D. 1998. Biological delineation of terrestrial buffer zones for pond breeding salamanders. Conservation Biology 12:1113-1119.
- Semlitsch, R.D. 2000. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management 64:615-631.
- Semlitsch, R.D., and J.R. Bodie. 1998. Are small, isolated wetlands expendable? Conservation Biology 12:1129-1133.
- Semlitsch, R.D., and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17:1219-1228.
- Sinsch, U. 1992. Structure and dynamic of a natterjack toad metapopulation (*Bufo calamita*). Oecologia 90:489-499.
- Sjögren, P. 1991. Extinction and isolation gradients in metapopulations: the case of the pool frog (*Rana lessonae*). Biological Journal of the Linnean Society 42:135-147.

- Skelly, D.K. 1997. Pond permanence and predation are powerful forces shaping the structure of tadpole assemblages. *American Scientist* 85:36-45.
- Skelly, D.K., E.E. Werner, and S. Cortwright. 1999. Long-term distributional dynamics of a Michigan amphibian assemblage. *Ecology* 80:2326-2337.
- Snodgrass, J.W., M.J. Komoroski, A.L. Bryan, Jr., and J. Burger. 2000. Relationships among isolated wetland size, hydroperiod, and amphibian species richness: implications for wetland regulations. *Conservation Biology* 14:414-419.
- Sperduto, D.D., and W.F. Nichols. 2004. Natural communities of New Hampshire. New Hampshire Natural Heritage Bureau and The Nature Conservancy. Concord, New Hampshire, USA.
- Sundquist, D., and M. Stevens. 1999. New Hampshire's Changing Landscape. Population growth, land use conversion, and resource fragmentation in the Granite State. The Society for the protection of New Hampshire Forests and The Nature Conservancy, Concord, New Hampshire, USA.
- Tappan, A., and M. Marchand (editors). 2004. Identification and Documentation of Vernal Pools in New Hampshire. New Hampshire Fish and Game Department Nongame and Endangered Wildlife Program, Concord, New Hampshire, USA.
- Tarr, T.L., M.J. Baber, and K.J. Babbitt. in press. Changes in the distribution and abundance of invertebrates across the hydrologic gradient. *Wetland Ecology and Management*.
- Tiner, R.W. 2004. Remotely-sensed indicators for monitoring the general condition of "natural habitats" in watersheds: an application for Delaware's Nanticoke River watershed. *Ecological Indicators* 4:227-243.
- Travis, J. 1994. Calibrating our expectations in studying amphibian populations. *Herpetological Review* 50:104-108.
- Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.
- Turtle, S.L. 2000. Embryonic survival of the spotted salamander (*Ambystoma maculatum*) in roadside and woodland vernal pools in southeastern New Hampshire. *Journal of Herpetology*. 34:60-67.
- Vos, C.C. and J.P. Chardon. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. *Journal of Applied Ecology* 35:44-56.
- Wellborn, G.A., D.K. Skelly, and E.E. Werner. 1996. Mechanisms creating community structure along a freshwater habitat gradient. *Annual Review of Ecology and Systematics* 27:337-363.
- Windmiller, B.S. 1996. The pond, the forest, and the city: spotted salamander ecology and conservation in a human-dominated landscape. Dissertation, Tufts University, Medford, Massachusetts.

Distribution of Vernal Pools in New Hampshire

Distribution
■ Known



0 10 20 40 Miles

