12 Conserving Vernal Pool Wildlife in Urbanizing Landscapes

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The phrase "vernal pool" has been in the news frequently of late and is gradually creeping into the lexicon of nonecologists in many parts of North America. Popular discussion of vernal pools often centers on perceived conflicts between developers bent on building office parks and subdivisions and wader-clad conservationists speaking of disappearing frog and salamander populations.

Historically, however, the public in North America has ignored these generally small and isolated wetlands. We had bigger swamps to drain, so to speak. When vernal pools were considered in popular circles it was most likely by mosquito control officers talking about the need to drain or poison these pestilential mosquito producers. Today, however, there are vernal pool conservation and education organizations in New England, Toronto, New York, and many other places in our subject region. Near some vernal pools, human spectators are almost as abundant as the migrating spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Rana sylvatica*) they have come to watch. Frogs and salamanders, once shunned as vermin (see references to the Second Plague, Exodus 8:1–11), are now all the rage in cuddly toys and tee shirts.

Perhaps many of us have developed a soft spot for vernal pools because they are so accessible to us. Throughout our region, an increasingly high percentage of people live only a short walk from a vernal pool, and this increase isn't due to the frogs and turtles moving into our backyards; rather, we are moving into theirs. In recent decades, humans in the northeastern U.S. and eastern Canada have abandoned dense frogless inner city neighborhoods to flock to new homes in sprawling suburbs or to exurban developments (residential development beyond the suburbs) in areas formerly dominated by agriculture and forestry. At the turn of the millennium, 79% of people in both Canada and the U.S. lived in areas defined by their respective governments as "urban" (as opposed to "rural"; sources: www.canadainfolink.ca/ and U.S. Census Bureau). In the same period, exurban, suburban, and urban land uses collectively consumed nearly half (49%) of the U.S. Eastern Temperate Forest ecoregion, a fivefold increase from 1950 (Brown et al. 2005). As our human population sprawls across the landscape, the rate of increase in newly urbanized acreage far exceeds the rate of human population growth (Theobald 2005; Johnson and Klemens 2005). Even where human population growth is stable or low, the redistribution of human populations is profoundly changing the natural landscape. Migration of people from urban areas to low density, large-lot residential development is increasing. The relatively new development practice of first clearcutting and grading larger lots and then replacing native plant communities with manicured lawns and gardens transforms amphibian habitat from forest to "nonhabitat" and fragments potential forested corridors that help to link wetlands.

Today, in much of our ecoregion, a turtle or salamander migrating to a vernal pool is far more likely to encounter lawns, roads, and buildings than cropland or clearcuts (Brown et al. 2005; Chapter 13, deMaynadier and Houlahan, for forestry impacts). Although agricultural impacts to vernal pools are not discussed in this volume, the effects of habitat loss on amphibian movement and summer and winter refugia are likely to be similar to effects from development. Urban landscape elements pose novel and severe dangers to vernal pool wildlife populations. Yet, until recently, relatively few researchers addressed the problems of vernal pool conservation in urbanized landscapes. In this chapter, we review the growing body of literature concerning the impacts of urbanization-related processes: forest loss and fragmentation, road kill and barriers to movement, and other edge effects, upon vernal pool wildlife, particularly amphibians and turtles. We also provide some general recommendations for vernal pool habitat conservation in urbanizing areas.

THE IMPACTS OF URBANIZATION ON VERNAL POOL WILDLIFE

Research in the past decade has provided much insight into the impacts of urbanization on vernal pool wildlife and has clearly demonstrated the need for landscape level conservation efforts that extend far beyond the border of a single vernal pool (Burke and Gibbons 1995; Windmiller 1996; Semlitsch 2002; Burne and Griffin 2005; Calhoun et al. 2005). The scope of this research is, however, uneven in its coverage. Although much has been learned about the relationship between wood frog (*Rana sylvatica*) and mole salamander (*Ambystoma* spp.) distribution and urban land cover, very little is known about the distribution of vernal pool invertebrates in human-dominated landscapes (Chapter 6, Colburn et al.). In eastern North America, most research on the effects of urbanization on vernal pool fauna has been conducted in the densely settled Boston–Washington corridor; fewer publications are available on urban impacts to vernal pools in eastern Canada, northern New England, and the Midwestern U.S. To date, correlational studies comparing vernal pool amphibian distribution to land cover are much more common than empirical studies examining the fate of particular amphibian populations following the construction of houses or other urban land cover within or near vernal pools. Finally, most research on vernal pools in urban environments has focused on documenting the impacts of urbanization on vernal pool wildlife; little is to be found in the literature on factors that favor the persistence of these same species in our increasingly urbanizing region. The sections that follow summarize these compelling, though incomplete, research findings on the various impacts of urbanization upon those vertebrate species most closely associated with vernal pools in our area: amphibians and turtles.

Direct Loss of Vernal Pools

Vernal pools have been lost to urbanization through complete or partial filling (Figure 12.1), draining, redirection of hydrological inputs, and the conversion of seasonally flooded pools into permanent ponds with fish (Colburn 2004). They have been destroyed for the purpose of converting land to human land-uses with higher economic value or in attempts to control mosquito populations (Chapter 6, Colburn et al.). Vernal pools are often small, seasonally flooded, and may be isolated from larger wetland systems (Chapter 2, Rheinhardt and Hollands). These characteristics make them particularly vulnerable to filling or direct alteration and also render vernal pools difficult to adequately protect through wetland regulations in the U.S. and Canada (Chapter 10, Mahaney and Klemens). In the Central Valley of California, King (1998) estimated that between 50 and 85% of presettlement vernal pool habitat had been destroyed, primarily through agricultural conversion. A recent study of historical wetland loss in the Nanticoke River watershed in Delaware and Maryland (Tiner 2005), found that the heaviest losses occurred among forested freshwater wetlands in either headwater or isolated landscape positions, precisely the type of wetland most likely to harbor vernal pool habitat in our region. Urbanization in the Northeast has resulted in the complete disappearance of vernal pools from many

FIGURE 12.1 Direct vernal pool destruction still occurs, despite wetland regulations. Here, a vernal pool is being drained prior to filling during construction of a single-family house in Plainfield, CT. Photo courtesy of Vin Mullin.

core urban areas and in large net losses of vernal pools in suburban areas. In the vicinity of Boston, Massachusetts, seven of the most densely populated municipalities have no potential or known vernal pools within their limits (MASSGIS data; Burne 2001). Even in less densely populated suburbs, vernal pools are often absent from town centers and disproportionately clustered within larger tracts of protected open space (Figure 12.2; A. Calhoun, R. Baldwin, and D. Oscarson, unpublished data). Grant (2005) recently reported that the probability of potential vernal pool occurrence in central Massachusetts was inversely correlated with the presence of urban or commercial development and high-density residential land cover. Windmiller et al. (B. Windmiller, I. Ives, and D. Wells, unpublished data) found a highly significant inverse relationship between potential vernal pool density (MassGIS data) and human population density among Massachusetts towns with densities greater than 300 people km^{-2} (776 people mi^{-2}), approximately the current median population density of Massachusetts.

We have been unable to find any estimates of recent rates of vernal pool destruction in northeastern North America. In states that have had the most stringent wetland and vernal pool regulations, direct vernal pool filling or draining has been a relatively uncommon phenomenon in recent years (In Connecticut: M. Klemens, Wildlife Conservation Society, personal communication; in New Jersey, J. Heilferty, New Jersey Department of Environmental Protection, personal communication; and in Massachusetts, B. Windmiller, unpublished data).

FIGURE 12.2 Cluster of vernal pools in high-quality forest surrounded by development in southern Maine (spring 2001, 1:12,000 CIR, Sewall Company, Inc.).

Loss of Neighboring Terrestrial and Wetland Habitat

As large swaths of amphibian and reptile habitat in northeastern North America are converted from forest to urban land uses (Brown et al. 2005), vernal pools become increasingly embedded within a human-dominated matrix of roads and houses. Windmiller (1996) found that developed land (i.e., residential, commercial, roads) constituted 43% of the land cover within 300 m (985 ft) of vernal pools in a suburban Massachusetts town, and Egan and Paton (in review) found a mean value of 22% developed land (including roads) within 1,000 m (3,280 ft) of 40 vernal pools in western Rhode Island. In Westford, MA, until recently a rural town, 39% of sampled vernal pools lost 10% or more of total forest cover within 300 m of the pool edge just in the period 1985–1999 (B. Windmiller, I. Ives, and D. Wells, unpublished data).

The consequences of preserving vernal pools but destroying adjacent terrestrial habitat are diverse and severe, including:

1. Reduction in the probability of amphibian population presence in otherwise suitable breeding sites (Windmiller 1996; Gibbs 1998; Homan et al. 2004; Rubbo and Kiesecker 2005; Clark et al., in review; Egan and Paton, in press). This trend shows a strong threshold effect, with the likelihood of presence decreasing sharply when forest cover declines below a certain level (threshold values of 44–51% forest cover within 1000 m reported for spotted salamanders and wood frogs by Homan et al. 2004, and Egan and Paton, in press.)
2. Reductions in the mean size of vernal pool-dependent amphibian populations and in the frequency of encountering relatively large populations (Windmiller 1996; Homan et al. 2004; Egan and Paton, in press).
3. Declines in wetland amphibian species richness with increasing urban land use (Lehtinen et al. 1999).

There have been few case studies to date documenting the effects of such habitat conversion on vernal pool amphibian populations. Windmiller et al. (in press) reported the extirpation of a small population of wood frogs in Massachusetts following the conversion of 90% of adjacent upland forest into a cinema complex. The same authors also observed sustained declines of greater than 40% in wood frog and spotted salamander populations after the loss of 41% of adjacent upland forest to a residential subdivision.

Similarly, there are few studies available on the effects of urbanization on the distribution of non-amphibian animal species associated with vernal pools. In densely human-populated urban environments in our region, aquatic and semiaquatic turtle species are uncommon and are likely to be confined to large (>1 ha; 2.47 ac) permanent wetland systems (B. Windmiller, personal observation). Although published research on the impact of urbanization on aquatic invertebrates of urban vernal pools is almost nonexistent (but see Brooks et al. 2002), studies of the invertebrate fauna of streams in highly urbanized contexts demonstrate lower levels of diversity compared to more rural landscapes (Moore and Palmer 2005). We likewise hypothesize that vernal pools in highly urbanized areas support fewer invertebrate species than pools in less developed landscapes.

Increased Road Mortality

As all vernal pool-dwelling reptile and amphibian species commonly move between pools and the surrounding landscape, increasing urbanization around vernal pools, and the concomitant increase in road and traffic density, is likely to cause increased mortality for reptile and amphibian migrants. Given their slow speed and tendency to stop and withdraw into their shells when startled, there is little chance that individual turtles can survive repeated crossings across roads with moderate or high traffic rates (Gibbs and Shriver 2002). Furthermore, it is likely that populations of aquatic turtle species that use vernal pools and other seasonally flooded wetlands undertake more frequent overland movements in response to unstable hydrological conditions than do populations of the same, or other, species that remain in permanently flooded wetlands throughout the year.

Turtle populations are particularly poorly equipped to absorb any incremental increase in adult mortality rates, given their generally long juvenile periods, relatively low reproductive rates, and low rates of survivorship among embryos and hatchlings (Congdon et al. 1993). Demographically, the impact of road mortality on turtle populations is exacerbated because gravid females often undertake long migrations to nesting sites (Joyal et al. 2001). Nesting females make up a disproportionately high share of the victims (Haxton 2000), and their loss is demographically costly to turtle populations. Recent research has confirmed that painted turtle (*Chrysemys picta*) and snapping turtle (*Chelydra sepentina*) populations in study areas in the northeastern U.S. have male-biased sex ratios and that the degree of male bias is positively correlated with road density in areas surrounding wetlands inhabited by the turtles (Marchand and Litvaitis 2004; Steen and Gibbs 2004). Studies of the long-term effects of roads on vernal-pool-associated turtle populations are lacking, but preliminary results from southern Maine are troubling (P. deMaynadier and

J. Haskins, unpublished data). In an attempt to reconfirm the presence of two state-rare vernal pool turtle species, spotted and Blanding's turtles, at sites where they had been originally documented at least 10–30 years previously, the researchers visited 88 vernal pools and pocket swamps where turtles are relatively easy to count using repeated binocular surveys. They reported significantly fewer numbers of Blanding's turtles from wetlands that were closer to major roads, concluding that the effects of road mortality and associated development may already be impacting local population distribution and trends (P. deMaynadier, personal communications).

Likewise, vernal pool-dependent amphibians are highly vulnerable to road mortality as adults move to and from vernal pools during breeding migrations and as newly metamorphosed juveniles disperse into the surrounding landscape. Ashley and Robinson (1996) demonstrated the vulnerability of amphibians to road mortality in a 3-year study in Ontario; of 32,000 dead vertebrates counted, comprising 100 species, amphibians constituted 92% of all casualties. As with turtles, the lethality of roads to migrating amphibians may stem from the slowness with which amphibians cross roads, particularly in cool temperatures. Amphibian vulnerability to mortality on the road is increased by a behavioral tendency among many species to "freeze" upon the approach of cars (Mazerolle et al. 2005). As a result, a high proportion of frogs and salamanders attempting to cross roads are killed even at low traffic densities (e.g., less than three cars per minute; van Gelder 1973; Hels and Buchwald 2001).

Several studies have demonstrated negative correlations between road density or traffic intensity and the abundance of some amphibian species. Fahrig et al. (1995) observed that the number of anuran choruses detected along road segments in Ontario declined with increasing traffic intensity. Vos and Chardon (1998), studying the temporary pool-breeding moor frog (*Rana arvalis*) in the Netherlands, calculated that the likelihood of finding moor frogs breeding in suitable habitat declined from 93% in pools with the lowest surrounding road density within the study area to 5% among pools with the maximum density of surrounding roads. Vos and Chardon (1998) calculated that the probability of moor frog occurrence was reduced by road proximity in 55% of a large study area in the Netherlands. Within our region, Egan and Paton (in press) found that road density in Rhode Island was negatively associated with spotted salamander and wood frog breeding population sizes in vernal pools at several spatial scales.

Barriers to Movement and Gene Flow

Roads can also act as barriers to the movement of vernal pool wildlife if individual animals simply avoid crossing them; such barriers may result in fragmented populations that manifest greater levels of inbreeding (Vos et al. 2001), sharper variations in demographic factors such as sex ratios and age class distribution, and other factors that predispose small, isolated populations to extirpation (Hels and Nachman, 2002; Chapter 8, Gibbs and Reed). Amphibian avoidance of roads (even unpaved ones) was demonstrated by deMaynadier and Hunter (2000) for eastern newts (*Notopthalmus viridescens*) and the mole salamanders, *A. maculatum* and *A. laterale*. Fahrig et al. (1995) encountered fewer amphibians (living or dead) per unit effort along roads with the highest traffic densities in their study (6–9 vehicles/min) compared to roads with lower traffic densities.

Besides roads, urban landscapes present other potential barriers to the movement of terrestrial animals between adjacent vernal pools and between vernal pools and other necessary habitats. Reh and Seitz (1990) observed that railroad tracks served to genetically isolate frog populations in the same manner as roadways. Likewise, large clearings, whether occupied by utility transmission corridors, golf course fairways, lawns, parking areas, or other anthropogenic land cover, may be avoided by some amphibian species, particularly salamanders (Windmiller 1996; deMaynadier and Hunter 1999; Rothermel and Semlitsch 2002; Mazerolle and Desrochers 2005; but see Montieth and Paton 2006). When amphibians do venture into fields and other areas cleared of forest cover, they may incur additional mortality and energetic costs as the result of a higher rate of water loss suffered while moving across open ground (Rothermel and Semlitsch 2002; Mazerolle and Desrochers 2005; Rothermel and Luhring 2005).

Other Edge-Related Effects of Habitat Fragmentation

As natural habitats become increasingly fragmented in urbanized landscapes, an increasing proportion of vernal-pool-associated animals encounter human-created habitat edges surrounding lawns, roads, and athletic fields during their migrations. Thus, vernal pool wildlife face increasing exposure to potentially harmful processes associated with urban land use. Many chemicals associated with urban environments are known to be toxic to amphibian adults and larvae, including road salt (Turtle 2000), fertilizers (Hecnar 1995), and biocides (Relyea 2005; Chapter 11, Boone and Pauli).

Proximity to houses and people can pose other hazards to vernal pool wildlife. Garber and Burger (1995) noted that a sharp decline in a wood turtle (*Glyptemys insculpta*) population in a Connecticut recreation area was associated with opening the land to human recreation and the likely removal of turtles as pets. Threatened and endangered turtle species, such as Blanding's (*Emydoidea blandingii*) and spotted turtles (*Clemmys guttata*) in eastern North America, may also have a commercial value deriving from their rarity; poaching of adults and eggs may be a local and growing problem (B. Butler, Oxbow Associates, Inc., personal communication). Turtles and amphibians inhabiting areas near houses and other human-created habitat edges may also suffer from an increase in densities of edge-associated mammalian and avian predators, and domestic carnivores (i.e., cats and dogs). Raccoons (*Procyon lotor*), for example, which may exist in much higher densities in proximity to people than in forested rural areas (Gehrt 2004), kill and injure adult turtles and are effective egg predators (Congdon et al. 1987). Raccoons and skunks also kill and sometimes consume wood frogs and spotted salamanders migrating to and from vernal pools (Vasconcelos and Calhoun 2004; B. Windmiller, personal observation). Finally, the abundance of exotic plant species in wetland and upland habitats increases in urban areas (Hansen et al. 2005; Chapter 5, Cutko and Rawinski). Such exotic species may alter the chemical environment and invertebrate species composition of forest soils (Hansen et al. 2005) as well as vernal pools with unknown direct and indirect impacts upon vernal pool wildlife.

PERSISTENCE OF VERNAL POOL ECOSYTEMS IN URBANIZED LANDSCAPES AND CONSERVATION OPPORTUNITIES

Fortunately, vernal pool wildlife species exhibit some degree of resistance and resilience to the impacts of urbanization. In some cases, relatively large populations of wood frogs, mole salamanders, spotted turtles, and other vernal pool wildlife can still be found in towns that are no longer rural. In suburban Massachusetts, Windmiller (personal observation) has observed a number of vernal pool amphibian populations, breeding close by the side of roadways, that have supported fairly high densities of car traffic for decades. Egan and Paton (in press) observed populations of wood frogs and spotted salamanders in landscapes with less than 15% forest cover in Rhode Island. Windmiller and colleagues have studied populations of wood turtles and spotted turtles, with well-represented juvenile age classes, inhabiting a drainage in densely settled Methuen, MA, sandwiched between an interstate highway and heavily trafficked state primary roadways (B. Windmiller and D. Wells, unpublished data).

Clearly, we cannot be certain how long specific populations of vernal-pool-associated amphibians and reptiles will persist in suburban or exurban landscapes in the face of road mortality, genetic isolation and other attendant hazards of living amidst burgeoning human populations. Unfortunately, historical data on the distribution and abundance of vernal pool wildlife populations are few, and analyses of the proportion of these populations that have persisted over decades in urbanized areas are unavailable. To date, studies of vernal pool wildlife in urbanized areas have focused, appropriately enough, on firmly demonstrating the negative consequences of urbanization.

Yet, exactly what percentage of the forest and other natural landscape features surrounding vernal pools needs to be preserved to yield a high probability of maintaining mole salamander or spotted turtle populations for decades to come? Furthermore, what habitat restoration or enhancement measures might be useful in mitigating damage to vernal pools and their adjacent terrestrial habitat matrix? To address these issues effectively, we will need future studies with a broadened focus. In addition to new research on the negative consequences of urbanization on vernal pool fauna, particularly invertebrates, we need an examination of the features of human-dominated landscapes most consistent with long-term persistence of vernal pool wildlife populations. What species can persist in human-dominated landscapes and how can we best design development practices to support them?

CONSERVATION RECOMMENDATIONS

Positive steps for conserving pool-breeding amphibian habitat in urbanizing landscapes can be taken. Specific recommendations for vernal pool conservation, particularly at the local scale, can be found elsewhere in this volume (Chapter16, Calhoun and Reilly) and in existing Best Management Practices (BMP) (Calhoun and Klemens 2002; Calhoun and deMaynadier 2004; Ovaska et al. 2004). Here we provide some general guidelines for practitioners in the field.

Inventory and Monitoring Opportunities in Urbanizing Landscapes

Our overarching recommendation for vernal pool conservation is for communities and interested parties to recognize that the existing knowledge base and regulatory frameworks afforded by state, provincial, or federal agencies is inadequate. There is no substitute for detailed local knowledge about the location of vernal pools, their ecological health, and current and future threats based on local growth patterns (Chapter 14, Baldwin et al.). Detailed knowledge of this sort may be expensive to gather and constrained by access to private property. Therefore, in cases where vernal pools may be impacted by development projects, developers should be required to provide as much detailed information about pools within the project areas as befits the scale of their projects. Detailed accounts of the responses of target organisms and communities to habitat disturbances caused by construction projects are invaluable for assessing future project impacts. It is reasonable to require developers to bear the brunt of appropriate monitoring costs needed to assess the long-term impacts of their projects on vernal pools and other biological resources. Specific recommendations for monitoring are provided in Windmiller et al. (in press) and a good discussion of analytical methods to assess the degree to which ecosystem functions recover from a disturbance can be found in Parker and Wiens (2005).

Avoid and Minimize

The primary strategy for pool conservation should be to direct development away from vernal pools and the adjacent terrestrial habitat. Potential vernal pools, many of which can be mapped remotely (Burne 2001), should be safeguarded (unless project proponents demonstrate that the wetlands involved do not meet regulatory or BMP definitions of vernal pool habitat). As adequate terrestrial habitat cannot be maintained around all vernal pools, conservation efforts will require the use of some system of ranking the relative ecological value of vernal pool systems (Calhoun et al. 2005; and Chapter 16, Calhoun and Reilly). The most commonly adopted measures of the ecological importance of vernal pools are the presence of locally rare or threatened species, egg mass counts of target amphibian species, and species diversity measures. Because these measures vary locally and regionally, they must be adapted to local conditions and needs.

Where development occurs within adjacent terrestrial habitats, impacts should be minimized by using management zone-based recommendations, as per Semlitsch and Bodie (2003) or Calhoun and Klemens (2002). BMPs for conserving vernal pool habitats generally use a concentric-circle model that represents a pool as a circle surrounded by radial management zones at distances established from data on pool-breeding amphibian movement patterns (see Figure 12.3). Current scientific

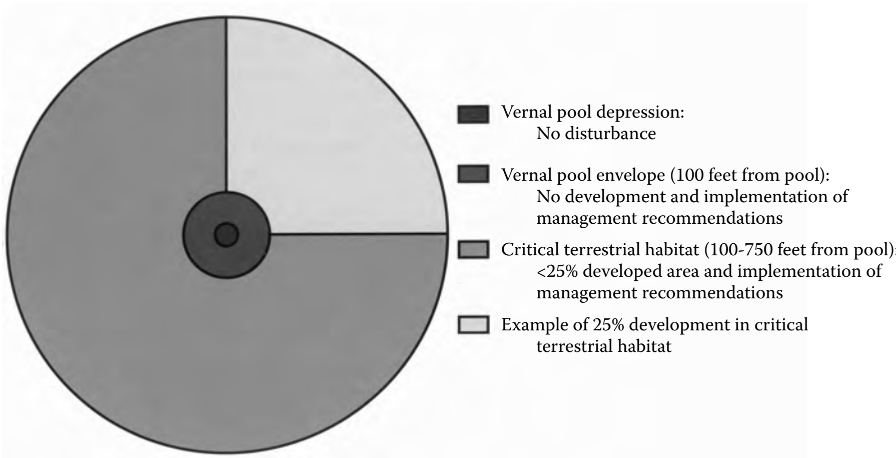

FIGURE 12.3 Suggested vernal pool management areas for pool-breeding amphibians. (From Calhoun, A.J.K. and Klemens, M.W. 2002. Best Development Practices: Conserving pool-breeding amphibians in residential and commercial developments in the northeastern U.S. MCA Technical Paper No. 5, Metropolitan Conservation Alliance, Wildlife Conservation Society, Bronx, New York. With permission.)

data suggest conserving terrestrial habitat in zones extending 150 to 300 m (500 to 1000 feet) from vernal pool boundaries (Semlitsch and Bodie 2003; Regosin et al. 2005). Above all, the purpose of BMPs and regulations is not to prevent development, but to redirect it (Preisser et al. 2000).

Mitigate Unavoidable Impacts

Direct loss of wetlands owing to filling or other alteration must be mitigated to ensure "no-net-loss" of wetland resources (Marsh et al. 1996; see Chapter 10, Mahaney and Klemens, for summary of wetland protections in Canada and U.S.). Compensatory tools include preservation of other wetlands, restoration or enhancement of wetlands, wetland creation, and in some cases, monetary compensation through mitigation banks or in-lieu fee programs (programs that require the developer to pay into an environmental fund administered by not-for-profits or government agencies; Gardner 2000). If loss is unavoidable, mitigation should focus on preservation of lands with existing natural vernal pool habitat (off-site or on-site), and restoration or enhancement of existing vernal pools and adjacent terrestrial habitat. The *de novo* creation of vernal pools in our region should be used as a last resort or should be coupled with one of the above strategies (see de Weese 1998). Created pools often fail to replicate vernal pool hydrology, and they may lure breeding amphibians away from more appropriate breeding areas (Vasconcelos and Calhoun 2004).

Vernal pools support diverse plant and animal taxa and the efficacy of mitigation strategies may vary among these taxa. For example, created pools inoculated with rare plants may function as habitat for rare plants, but may fail to support the suite of amphibians and invertebrates associated with pools typical of the region. Invertebrate communities may change more dramatically than do amphibian communities in response to differences in hydroperiod (Colburn 2004), making replacement of natural invertebrate communities more difficult. We urge practitioners to clearly express their mitigation goals and to clearly articulate the methods that will be used to assess the success or redress the failure of the mitigation project.

Preservation, Restoration, and Enhancement

Given the complexity of vernal pool habitat (pool and adjacent terrestrial zones) and the spatial and temporal needs of pool-breeding amphibians (Chapter 7, Semlitsch and Skelly), conservation of intact habitat should be the primary goal of pool mitigation projects. However, preservation still results in a net-loss of wetlands and is often prohibitively expensive due to high land prices associated with rapidly urbanizing areas.

The restoration and enhancement of degraded vernal pool habitat is another option. Agricultural fields, clearcuts, pasture, and other lands lacking impermeable surfaces, but that have historically supported pools, are good options for mitigation, assuming that there is suitable adjacent habitat. Additionally, there is much room for creative study and practice of restoration and enhancement techniques for adjacent terrestrial habitat around vernal pools (Windmiller 2006). Turtle nesting sites, for example, may be fairly easy to create and the availability of such nesting sites may be an important limiting factor for vernal pool-associated turtle species in some areas. Spotted salamanders are also known to distribute themselves nonrandomly in forested habitat surrounding breeding sites, and their density may be influenced by small mammal burrow density (Regosin et al. 2004) and possibly other types of natural crevices (Windmiller 2006). Once we know more about key habitat parameters for pool-breeding amphibians, forested habitat could be restored or enhanced.

Vernal Pool Creation

In our region where natural pools are still a common feature in less-developed landscapes, creation should be a last resort or should be coupled with preservation or restoration of vernal pool habitat. The National Research Council (2001) has identified vernal pools as the most difficult wetland to create. Lichko and Calhoun (2003) reviewed vernal pool creation projects in New England and found that most were unsuccessful in replacing vernal pool functions and lacked sufficient monitoring of those functions. It is particularly challenging to recreate the seasonal hydrology characteristic of vernal pools (Beaulieu 2006). There is a risk that inappropriately created vernal pool habitat will function as biological sinks or areas that attract breeding but do not support successful development of larvae to subadults. Additionally, newly created pools are often made at the margins of developed landscape where the wildlife species that use them are subject to potentially harmful edge effects as described above (e.g., pollution, high predation, and illegal collection).

Given that vernal pool creation will be adopted, in some cases, as a mitigation measure, we offer some general guidance to ensure a higher rate of success if creation is among the strategies for compensation. Also note that the Native Plant Society of California (de Weese 1998) has published detailed policy guidelines for vernal pool mitigation. Refer to these guidelines for a more in-depth discussion of each tool. Although plant and invertebrate pool specialists are the conservation focus, their guidelines are generally suitable for pools in our region as well (see also de Weese 1998).

- Collect baseline data on the pools being lost and on the wildlife populations that use them. Given the high natural variability in breeding population sizes and migratory patterns of many vernal pool amphibians and reptiles, multiyear baseline data is important to obtain, when possible (Windmiller et al., in press).
- When creating vernal pools, one should inventory natural pools and their associated wildlife populations in the project area. These may serve as paired controls in determining the effectiveness of the created vernal pools (Parker and Wiens 2005) and are also likely to serve as a source of colonizing animals.
- If creation is the only option, one should consider coupling creation with the preservation or restoration of existing vernal pools so that the mitigation ultimately makes a solid positive contribution to the resource (see California Native Plant Society mitigation guidelines, deWeese 1998);
- Postconstruction monitoring protocols should, if possible, exceed the 3–5 year period required by most regulatory agencies (deWeese 1996; Zedler 1996; Lichko and Calhoun 2003; Petranka et al. 2003a; Petranka et al. 2003b; Vasconcelos and Calhoun 2006; Windmiller et al., in press).
- Pools created for mitigation should be subject to following BMPs.
- Some artificial pools may be successful (e.g., former gravel pits, borrow pits, or pools created by road blockages). Many created pools have longer hydroperiods than natural pools and may be persistent during droughts. However, this longer hydroperiod will be suitable only for a subset of vernal pool flora and fauna. For this reason, creation may target a subset of pool-breeding fauna. Guidance for creating vernal pools has been published and should be consulted when mitigation includes creation of pools (Biebighauser 2003). However, the long-term success of created pools is still not well documented. We recommend that vernal pool creation projects take into account the caveats listed above and that results are studied at a sufficient scale in space and time to determine the effectiveness of the creation.
- Always consider the following: What vernal pool functions need to be replaced? Which species are targeted? Does the mitigation strategy result in net loss of wetland? How and when will the successful attainment of these goals be measured and judged? What specific strategies will be considered if the results fall short of expectations, and who will fund them?

Mitigation Banking or In-Lieu Fee Programs

Monetary compensation for wetland losses in the form of mitigation banks and in-lieu fee programs is becoming increasingly popular in Canada and the U.S. Seen as an economically efficient way to offset ecological impacts to resources, banks and fee programs offer a creative alternative to on-site compensatory mitigation (Marsh et al. 1996; Gardner 2000; Stein et al. 2000). Criteria for debits/credits and compensation ratios should be tailored to the vernal pool resource, and this may best be done at local scales (Brown and Lant 1999).

Use Published BMPs as Models, Not Gospel

Research on the ecology and conservation of vernal pool wildlife in urbanizing regions is still preliminary and very spotty in its coverage. Existing BMPs (e.g., Calhoun and Klemens 2002; Calhoun and deMaynadier 2004), were tailored to scientific data available when they were written, therefore they must be viewed as provisional best-attempts to provide useful recommendations. BMP models are generally designed to be used at the local scale and, as such, must be tailored to meet specific local conservation needs. For example, egg mass count thresholds for biological significance of pools will vary with region. Terrestrial habitat zones may not follow a concentric-circle pattern. In some cases it may be more economically feasible and ecologically effective to use directional management zones that target specific key nonbreeding habitat elements (e.g., forested swamps for wood frogs; Baldwin et al. 2006). Movement patterns of vernal pool wildlife are nonrandomly distributed in adjacent terrestrial habitat (Shoop 1965; Windmiller 1996; Vasconcelos and Calhoun 2004; Patrick et al. 2007). Rather than purchasing or protecting inappropriate habitat equally around the pool (per the concentric circle model), towns could save money and minimize conflicts by ensuring conservation of lands relevant to the terrestrial needs of the specific pool-breeding fauna locally present. In short, be flexible and creative in your application of BMPs to local landscapes.

SUMMARY

The bad news for people interested in conserving vernal pool wildlife in urbanizing landscapes is manifest. Urbanization results in the loss of vernal pools and in the loss and fragmentation of terrestrial habitat integral to vernal pool communities. The consequences are severe: rapid extirpation of some populations and the endangerment of others through genetic isolation and increased mortality rates. Urbanization kills vernal pool amphibians and reptiles in ways as diverse as the urban landscape, ranging from direct habitat loss to a host of edge-related effects when vernal pool habitat is brought into proximity with houses, roads, and lawns.

The good news is that vernal pools and most of the species that use them are still generally widespread in our region and show some degree of resilience in the face of urban sprawl. Moreover, recent BMP guidelines for vernal pool conservation offer guidance for redirecting development in ways that will, hopefully, minimize ensuing negative consequences to vernal pool wildlife.

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