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Conserving pool-breeding amphibians in human-dominated landscapes through local implementation of Best Development Practices

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Abstract

Seasonal forest pools in the northeastern USA are unique ecosystems whose functions are intimately associated with adjacent upland habitats. This connection, coupled with their small size and ephemeral surface water, has made conservation of pool resources challenging. Seasonal pools provide optimal breeding habitat for animals adapted to temporary waters including ambystomatid salamanders (*Ambystoma* spp.), wood frogs (*Rana sylvatica* LeConte), and some invertebrates and plants. To date, wetland conservation efforts have been primarily limited to 2 pathways: land use regulation and preservation. Although both of these pathways have the potential to conserve some pool resources, they are often insufficient to maintain an array of pools in the landscape that support local population dynamics of amphibians. We propose a third pathway – local land-use planning – that can complement regulatory and preservation efforts. This suite of strategies, embodied in our Best Development Practices (BDPs), recognizes that not all pools will be conserved; local governances will need to develop priorities for conservation. The BDPs encourage local governances to (1) proactively identify their pool resources, (2) rank those pools according to their relative ecological value, and (3) establish management procedures and apply recommended guidelines in accordance with the relative rankings. We recommend that pools be ranked using biological criteria (e.g., presence of listed species, presence of breeding species, and egg mass abundance) and on the availability and quality of adjacent terrestrial habitat. We recommend 3 management zones: the pool depression, the pool envelope (i.e., land within 30 m of the pool), and the critical terrestrial habitat (i.e., 30–230 m from the pool). Residential, industrial, and commercial development, which may compromise pool habitat (e.g., through building and road construction, site clearing, stormwater management, and lighting), should follow the recommended guidelines presented in Appendix 1 of this paper. Planning at the watershed level, using such tools as overlay zones, wetland ordinances, and easements, should lead to more effective, long-term management of, at a minimum, the most ecologically important seasonal forest pool resources and will provide developers with clear development guidelines. This process is already being successfully implemented in a number of New England towns.

Introduction

Seasonal forest pools, also called vernal pools, woodland vernal pools, ephemeral wetlands, or temporary wetlands, are unique ecosystems that perform important functions, but conservation of pool resources has proven to be challenging (Semlitsch 1998; Klemens 2000; Snodgrass et al. 2000; Marsh and Trenham 2001; Calhoun et al. 2003). Interest in seasonal forest pools has increased dramatically in the eastern USA in the last decade because of the well-publicized declines of amphibians (Alford and Richards 1999; Carey et al. 1999; Young et al. 2001), many of which depend on seasonal forest pools or other isolated wetlands for breeding (Pechmann et al. 1991; Lannoo 1998). To date, wetland conservation efforts have been limited to two pathways: land use regulation and preservation. Although both of these pathways have the potential to conserve some pool resources, they usually don't include mechanisms to maintain adjacent terrestrial habitat and connections among pools in an otherwise fragmented landscape. In this paper, we propose a third pathway – local land-use planning – to complement regulatory and preservation efforts through voluntary approaches.

Seasonal pools; other small, isolated wetlands; and the adjacent terrestrial habitat required by wetland-dependent animals have received little or no protection by wetland regulatory authorities at either federal or state levels (Fretwell et al. 1996; Preisser et al. 2000; Snodgrass et al. 2000). In a recent U.S. Supreme Court decision ([January 9, 2001], Solid Waste Agency of Northern Cook County [SWANCC] v. United States Army Corps of Engineers [Corps]), the Court held that the Corps had no jurisdiction over isolated waters based solely upon the use of the waters by migratory birds (i.e., 'Migratory Bird Rule'), and that Congress did not intend Section 404 of the Clean Water Act to include Corps regulation of such isolated waters. The extent to which this ruling will affect protection of seasonal pools and other isolated wetlands in the northeastern U.S. remains to be seen, but already it has sent the message to states and other jurisdictions that conservation of isolated wetlands is not a priority.

States in the northeastern USA have wetland protection statutes that regulate human activities in jurisdictional wetlands at a level equal to, or more stringent than, federal regulations. Specific regulatory programs and permit processes vary from state to state (Preisser et al. 2000), but small wetlands, including seasonal forest pools, receive the least protection under most state regulatory programs. Some states (e.g., Rhode Island, Maine, Massachusetts) have special language for pool protection, but in all cases, protection of adjacent terrestrial habitat for amphibians is limited or non-existent (Calhoun and Klemens 2002).

The second pathway, preservation, is not feasible for conserving pool resources of sufficient quality and in sufficient quantity to ensure the long-term viability of pool-breeding amphibian species and populations. Preservation efforts should be applied wherever high-quality pools exist, because preservation can be more successful than regulations at protecting the critical terrestrial habitat surrounding pools. However, numerous individual pools scattered throughout the landscape are harder to include in preservation plans than a single, large wetland.

There is a need to create a new pathway to conserve pool resources that can complement state regulatory programs and preservation efforts: better local land use planning. At the local level, this can be voluntary or codified in land use ordinances (local regulation). Sprawl, or poorly planned land development, is one of the primary causes of habitat loss, which, in turn, has been identified as one of the primary threats to biodiversity (Wilcove et al. 1998; Kirkman et al. 1999; Semlitsh 2003). Research-based management recommendations tend to target conservation at either (1) broad federal, state, or regional scales, or (2) on a site-specific basis. Yet many of the decisions that drive sprawl are made at the local level by town planners, planning and zoning board members, and others who lack knowledge of basic ecological principles and site-specific natural resources. Conservation of pool-breeding amphibian habitat is often most effective at the local level where neighbors, planners, and other concerned citizens play an active stewardship role (Klemens 2000; Preisser et al. 2000). Since the vast majority of land use decisions are made at local levels (Theobald et al. 2000), equipping local land use decision makers with the knowledge and tools necessary to make ecologically informed decisions may be the most effective way to reduce the impacts of sprawl. Translation of 'best available science' into management strategies, or, in this case, Best Development Practices (BDPs), is a step in the right direction.

This paper demonstrates how such tools and knowledge can be provided to land use practitioners. The BDPs we present here are being implemented in towns in the northeastern U.S. and serve as a model for local planning efforts to conserve seasonal wetlands and the adjacent terrestrial habitat (D. Oscarson, unpublished data). We summarize these strategies for local governances (see Calhoun and Klemens 2002 for more detailed BDPs for towns). Specifically, we highlight the habitat function of seasonal forest pools, including a summary of common development activities most likely to negatively alter these habitat functions, and provide guidance to local governances on how to (1) proactively identify their seasonal forest pool resources, (2) rank pools according to their relative ecological value, and (3) develop management procedures that correspond to the relative rankings. We also include recommended guidelines for development activities associated with pools to be implemented on a pool-by-pool basis or to be adopted as protocol at a landscape scale (see Appendix 1).

Seasonal forest pools as wildlife habitat

The definition of seasonal forest pool, or vernal pool, varies among states, resource managers, and scientists (Calhoun and Klemens 2002). In general, and for the purposes of our guidelines, seasonal forest pools are ephemeral to semi-permanent pools that attain maximum depths in spring, and lack permanent surface water connections with other wetlands or water bodies. Pools typically fill with snowmelt or runoff in the spring, although some may be fed primarily by groundwater sources and may begin to refill in the fall. Hydroperiod varies among pools and within pools annually; it ranges along a continuum from less than 30 days to years (Semlitsch 2000). Pools are generally <0.4 ha, with the extent and type of vegetation varying widely. In the northeastern U.S., they provide optimal breeding habitat for animals adapted to temporary, fishless waters including, but not limited to, *Ambystoma* spp. (ambystomatid salamanders), *Hemidactylium scutatum* Tschudi, *Rana sylvatica*, *Scaphiopus holbrookii* Harlan, and *Eubranchipus* spp. (Hunter et al. 1999; Calhoun and Klemens 2002). In addition, seasonal pools provide foraging and resting habitat for a number of state-listed species including *Clemmys guttata* (Schneider), *C. insculpta* (Le Conte), *Emydoidea blandingii* (Holbrook), and *Thamnophis sauritus* (L.).

Despite their small size and lack of hydrologic connection to permanent water bodies, seasonal forest pools are important landscape components. They make up the vast majority of the total number of wetlands in the landscape and, because of their small size, hydrology, and predominantly private ownership, are wetlands at high risk of loss (Gibbs 1993; Semlitsch and Bodie 1998; Snodgrass et al. 2000). Functionally, seasonal pools provide a network of wetland oases in otherwise forested landscapes. They export biomass, in the form of amphibians and invertebrates, to the adjacent uplands and sustain wetland-dependent wildlife by providing foraging and resting areas and moist, summer refugia (Gibbs 1993, 2000; Semlitsch 1998; 2002; Semlitsch and Bodie 1998; Calhoun and Hunter 2003). Pool-dependent fauna occur in clusters of local populations that are sustained through occasional movements (i.e., colonization, dispersal, migration) among wetlands (Hanski and Gilpin 1991; Gibbs 2000; Semlitsch 2003) and require multiple landscape elements (i.e., wetlands and uplands) to complete their life cycles (Dunning et al. 1992; Dodd and Cade 1997; Pope et al. 2000).

The effects of silvicultural practices on amphibian populations, particularly woodland salamanders, have been widely addressed in the literature (Ash 1988; deMaynadier and Hunter 1995; Calhoun and deMaynadier 2004). There is less published information on the effects on amphibian populations of fragmentation from development in human-dominated landscapes and, to our knowledge, there are no specific recommendations addressing the management of terrestrial habitat for pool-breeding amphibians. Typical regulatory buffers around wetlands range from 15 to 30.5 m, an adjacent terrestrial area insufficient to meet the life history needs of pool-breeding amphibians (Semlitsch 2002; Calhoun and Hunter 2003; Miller and Klemens, in press). Regulatory strategies that focus on protecting only the breeding pools will most likely fail to maintain healthy amphibian populations; protection of critical terrestrial habitat must also be a priority (Windmiller 1990; Semlitsch 1998; Lehtinen et al. 1999; Gibbs 2000;

Semlitsch 2002). Other factors that put pool-breeding amphibian populations at risk in development contexts include spatial isolation of pools and local populations (Berven and Grudzien 1990; Brooks et al. 1998; Semlitsch 2003) and various development practices that degrade habitat quality in pools and in adjacent terrestrial areas. Conversion of natural habitats to impervious surfaces may result in altered hydrologic regimes (Ferguson 1994). Roads may be sources of runoff containing chemicals and pollutants that degrade breeding habitats (Turtle 2000; Forman et al. 2003), while alteration of forested habitat around pools, and use of pools as stormwater detention basins, may also degrade water quality (Keddy 2000).

Roads and stormwater management systems, which are numerous in human-dominated landscapes, have negative effects on amphibian populations either through direct mortality or by acting as barriers to dispersal (Klemens 1990; Fahrig et al. 1995; Gibbs 1998; Lehtinen et al. 1999; Mitchell and Klemens 2000; Egan and Paton 2004). Site clearing around pools for roads or other hard structures alters and eliminates critical overwintering habitat (Windmiller 1996; Regosin et al. 2003a).

Development activities often lead to the creation of new wetlands, as a result of regulations intended to mitigate loss of natural wetlands. These newly created wetlands often lack the structural diversity, microhabitats, and hydrology to support pool-breeding amphibians (DiMauro and Hunter 2002; Lichko and Calhoun 2003; Vasconcelos 2003). Such wetlands can intercept amphibians as they disperse to breeding pools; eggs laid in these 'decoy' wetlands often do not survive.

A variety of other post-construction issues following development (e.g., attraction or introduction of pest species that prey on amphibians, increased use of pesticides, and light spillage) may cause local declines in pool-breeding amphibian populations (see Calhoun and Klemens 2002, for a more detailed discussion). Potential management solutions to these threats are provided in Appendix 1.

Best Development Practices

The BDPs we present here are based on our current understanding of pool-breeding amphibian ecology, terrestrial habitat requirements, and how best to maintain local populations in developing landscapes. BDPs are recommended strategies for conserving the wildlife habitat value of seasonal forest pools and their adjacent terrestrial habitat. They may be voluntary or codified through local regulatory mechanisms. Implementation of the BDPs will enable communities to develop long-term, proactive plans for the protection of pool resources as a subset of their overall master planning process. Therefore, citizens and developers may view town management of pools as consistent and predictable, and as a legitimate part of the jurisdiction's accepted and approved development goals. The BDPs include general local planning and pool assessment strategies, as well as specific recommended management zones and guidelines for development activities associated with seasonal forest pools. The management zones and guidelines may be applied on a pool-by-pool basis, or incorporated into governance-wide planning strategies. We suggest three sequential steps for local conservation of pools: (1) mapping and inventory of pools, (2) ecological assessment of pools, and (3) development of conservation plans. Specific recommended guidelines for development activities near pools are provided in Appendix 1.

Planning and assessment

Mapping and inventory

The goal of local inventory and mapping is to identify exemplary pools or pool clusters in each community. This enables decision-makers, developers, and citizens to understand which sites are of special significance as a community resource. Inventory methods will vary according to the availability of resources, the region of interest, and level of expertise available. Some breeding pools can be located by using aerial photography or National Wetland Inventory (NWI) maps (see Burne 2001 for a primer on identifying and mapping seasonal pools using aerial photography and Geographic Information Systems [GIS]). Before beginning the inventory process we recommend that jurisdictions locate existing aerial photography or wetland maps, and assess the skills and expertise available through volunteers. Funding sources may be available for conducting a professional inventory or, alternatively, local educational institutions, land trusts, or non-profit organizations may be able to lend support.

Pools, and clusters of pools, may be located using maps, aerial photographs, ground surveys, or a combination of these techniques. If possible, a Geographic Positioning System (GPS) should be used to obtain coordinates, to facilitate creation of a seasonal pool data layer in a Geographic Information System.

Ecological assessment: prioritizing conservation targets

We recognize that it is not economically or politically feasible for local governances to protect every pool. For this reason, pool resources must be assessed and priorities for protection must be established. Examining pools in the field and collecting biological data can determine each pool's relative regional or local importance. Trained volunteers, town officials, or professional biologists can collect these data (D. Oscarson, unpublished data). Pools, or clusters of pools within a town, may vary tremendously in quality or ecological significance. In general, we recommend that local governances focus their conservation efforts on pools with relatively undeveloped adjacent terrestrial habitat and ecologically significant pools representing a range of size and hydroperiod (see Tier ratings below). In order to protect a wide diversity of pool-breeding invertebrates and amphibians, pools with long-term conservation opportunities (e.g., pools on public land, not-for-profit lands, or in large tracts of relatively undisturbed private ownership) should be targeted. Maintaining or restoring the adjacent terrestrial habitat for pools in agricultural or suburban settings where the amount of forest cover is limited is an option for long-term management of otherwise productive pools.

Rating the ecological significance of an individual pool is not a simple process. For this reason, we provide general guidance for assessment of pool ecological significance based on two parameters: (1) biological rating or value of the pool and (2) condition of the adjacent terrestrial habitat (Table 1). The biological rating is based on species abundance, species diversity, and presence of federal- or state-listed species. Assessment of the adjacent terrestrial habitat includes the integrity of the pool's envelope (i.e., land within 30 m from the pool's edge) and critical terrestrial habitat (i.e., land from 30–230 m from the pool's edge). To assist in this process, we developed tier ratings (i.e., prioritizing for protection) based on the pool's biological attributes and the condition of the adjacent habitat (Table 2). Tier 1 pools are top priority for protection.

The biological criteria presented in Table 1 are fairly straightforward with the exception of the egg mass abundance criterion. The egg mass threshold should be treated as a guideline, not as an unchangeable rule. Data on the percentage of biologically active pools, based on numbers of egg masses and on species presence, that are necessary to maintain local pool-breeding amphibian populations in any given area have

Table 1. Seasonal pool ecological assessment criteria.

A. Biological Value of the Vernal Pool

(1) Are there *any* state-listed (Endangered, Threatened, or Special Concern) species present or breeding in the pool?
Yes_____ No_____

(2) Are there two or more vernal pool indicator species (see Table 3) breeding (i.e., evidence of egg masses, spermatophores [sperm packets], mating, larvae) in the pool?
Yes_____ No_____

(3) Are there 25 or more egg masses (regardless of species) present in the pool by the conclusion of the breeding season?
Yes_____ No_____

B. Condition of the Critical Terrestrial Habitat

(1) Is at least 75% of the vernal pool envelope (100 feet from pool) undeveloped[1]?
Yes_____ No_____

(2) Is at least 50% of the critical terrestrial habitat (100–750 feet) undeveloped?
Yes_____ No_____

[1] "Undeveloped" land is defined as open land largely free of roads, structures, and other infrastructure; undeveloped land may include forested or partially forested land, shrubland, or open agricultural land.

Table 2. Ranking of seasonal pools based on assessment criteria.

No. of questions answered YES in Table 1, Category A	No. of questions answered YES in Table 1, Category B	Tier Rating
1–3	2	Tier I
1–3	1	Tier II
1–3	0	Tier III
0	1–2	Tier III

not been published, although modeling efforts to provide this guidance are underway (P. deMaynadier, unpublished data). Ideally, the goal should be to maintain natural density and historical distribution patterns (see Stone 1992; Brooks et al. 1998; and Calhoun et al. 2003 for pool density estimates in New England), although this may be possible only in less developed portions of a region. In the absence of models or guidance from the literature, we chose 25 egg masses as a threshold for ecological significance based on egg mass count data from New England that were available at the time of publication of the original BDPs (see Calhoun and Klemens 2002). The intent of the 25 egg mass threshold was to include at least half of located pools, while eliminating inclusion of secondary breeding sites such as incidental roadside ditches and skidder ruts. Data obtained more recently (e.g., Crouch and Paton 2000; Middlesex County Soil and Water Conservation District 2000; Calhoun et al. 2003; Egan and Paton 2004; R. Baldwin, unpublished data; B. Windmiller, unpublished data; D. Oscarson, unpublished data) indicate that this threshold should be set substantially higher, at least in southern New England, perhaps in the range of 40 to 60 egg masses. Because egg mass numbers vary regionally and annually, and because new data and analyses can continually refine the BDP process, each local governance should ideally complete its own biological inventory and determine the local threshold for this criterion based on inventory results.

In the seasonal pool assessment (Table 1), less than 25% of the area within the first 30 m of the pool edge and 50% or less of the remaining adjacent terrestrial habitat out to 230 m must be undeveloped for a pool to be rated Tier I or II. However, management goals for the terrestrial zones are more stringent: no disturbance within the first 30 m of the pool edge, with only 25% of the remaining terrestrial habitat developable (see Figure 1). The few studies that have been conducted on this topic suggest that development (i.e., buildings, impermeable surfaces, roads, lawns) that impacts 25–30% or more of the habitat surrounding pools causes local declines in breeding populations of amphibians (J. Gibbs, unpublished data; B. Windmiller, unpublished data). The assessment criteria are less stringent than the overall management recommendations because the uplands surrounding pools within developing landscapes have often already been compromised. Higher management standards are recommended to reduce development pressures in the critical zones of pools that occur in developing landscapes. In such cases, restoration may also reverse previous impacts.

Development of conservation plans

Local decision-makers can target high priority pools and pool clusters, identified by their inventory and assessment, for local protection.

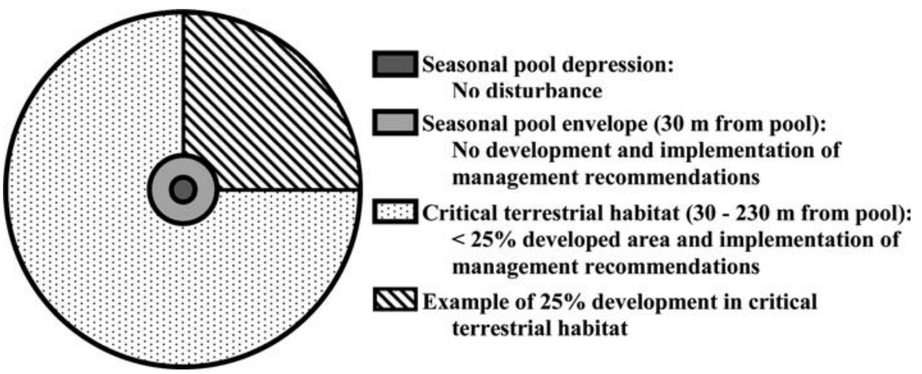

Figure 1. Seasonal pool recommended management zones and corresponding management recommendations.

The driving impetus for this priority setting exercise is that protecting a smaller number of high-priority pools is preferable, from a conservation standpoint, to protecting a greater number of pools that lack the critical terrestrial habitat, or the potential to restore such habitat, needed to sustain populations of pool-breeding species. From a developer's perspective, priority setting provides certainty as to where locally important, significant resources are located. This should replace the *status quo* of strong opposition to almost every development near a pool, regardless of the relative ecological viability of the pool. Once conservation priorities are established, there are a variety of mechanisms that local jurisdictions may employ to achieve these goals. Some of these are presented below.

Incorporation into comprehensive, development, or master plans

Community comprehensive plans should incorporate the goals of these pool protection strategies, justification for those goals, and locations of exemplary pools that have been targeted for stewardship. There are 2 primary reasons for doing this:

(1) *Clarity* – It is very important that all stakeholders (i.e., property owners, citizens, developers, and local decision-makers) are aware of the goals of pool protection and which properties are considered essential to achieving those goals. This provides some level of certainty in what can be a chaotic case-by-case debate.

(2) *Security* – If a community clearly articulates its goals and objectives in a written, publicly adopted document, and then consistently follows those guidelines, it is less susceptible to legal challenges. Legal challenges against municipal decisions are most successful if it can be demonstrated that those decisions are capricious, without reasoned basis, and therefore inconsistent with a community's articulated goals and policies.

Acquisition

Land acquisition is expensive and therefore not often feasible for communities. However, under certain circumstances it might be possible for a community or land trust to acquire key properties. We recommend acquisition of individual Tier I pools; the acquisition should target a minimum of 230 m of land from the pool depression in all directions. In addition, acquisition efforts are appropriate for large blocks of undeveloped land with clusters of pools of any tier.

Easements

On subdivision projects where undeveloped land with seasonal forest pools is reserved, we recommend that the developer convey a conservation easement to a local land trust, the municipality, or a conservation or scientific not-for-profit organization. In our experience this conservation strategy is far superior to reliance on a homeowner's association to protect these resources. The holder of the easement would be responsible for ensuring that the terms of the easement are being met, and for informing the neighbors about the stewardship needs of the property.

Overlay zones

The town can adopt a resource overlay zone specifically designed to protect high-priority seasonal pools. Resource overlay zones leave existing town zoning in place while applying additional development standards, requirements, or incentives in the overlay zone. This would be particularly effective where clusters of Tier I and Tier II pools occur, or where pools display a range of hydroperiods. We recommend that towns adopt a resource overlay zone to encompass those pools and critical terrestrial habitats that have been designated as protection priorities. The zone could provide a mix of regulations, including compliance with the Recommended Guidelines in Appendix 1, and incentives to conserve pools and preserve economic equity (see Calhoun and Klemens 2002).

Wetland ordinances

Some jurisdictions have developed ordinances specifically to protect seasonal pools and their associated terrestrial habitat. Rather than use rating systems that place undue emphasis on number of species present or size of pools, we recommend using the BDPs as a foundation for seasonal pool management.

Recognition and voluntary stewardship programs

Programs that encourage pool stewardship could be set up to provide technical advice and recognition to landowners who voluntarily protect and manage these resources; programs could also provide training for municipal officials. Another approach would be to publicly recognize those developments that adhere to pool BDPs. Apart from demonstrating that it is possible to develop responsibly, such recognition may be an important marketing tool. For example, in Farmington, Connecticut, USA., a small development has been created that has turned a pool and its resources into the centerpiece of the development and its marketing of the project.

Management zones and goals for seasonal forest pools

To this point, the BDPs have focused on conservation of pool-breeding amphibian habitat at a landscape scale necessary for local planning initiatives. Below, we provide guidance for management of pools that can be applied to all the exemplary pools within the watershed or that can be applied to individual pools. This may be particularly useful for land use decision makers faced with approving development activities on a case-by-case basis.

We define three pool management zones (Figure 1), based on known travel distances and habitat-use patterns of some pool-breeding amphibians in the northeastern USA (Table 3). These are the pool depression, the pool envelope (i.e., the area within 30 m of the pool edge), and the critical terrestrial habitat (i.e., the area 30–230 m from the pool edge). This total recommended conservation zone of 230 m differs from the 122-m zone proposed by Calhoun and deMaynadier (2004) for best management practices for forestry because of landscape context. In managed forests, logged areas may regenerate to forest and will provide shade and cover in a relatively short period of time. However, in the context of development, built-up areas are typically permanently lost as terrestrial habitat or as travel corridors.

Adult travel distances from natal pools have been documented through radio-tracking of individual adult salamanders and through pit fall arrays (Semlitsch 1981; Madison 1997; Madison and Farrand 1998; Faccio 2003; Vasconcelos 2003; R. Baldwin, unpublished data). Ambystomatid salamanders and ranid frogs often travel hundreds of meters to and from breeding ponds and among wetlands during the non-breeding season (Semlitsch 2002; Regosin et al. 2003a). Reported maximum travel distances from breeding pools for adult abystomatid salamanders range from 198 m for adult *A. laterale* Hallowell to 625 m for *A. jeffersonianum* Green. Mean reported distances traveled from natal pools range from 130 m for A. *maculatum* Shaw to 213 m for *A. jeffersonianum* (Faccio 2003). Juvenile *R. sylvatica* have been documented traveling as far as 472 m from natal pools, while adults have been documented summering over 300 m from their natal pools (Vasconcelos 2003; R. Baldwin, unpublished data). Our proposed conservation zone of 230 m falls within the range of the 160–290 m amphibian critical core habitat around wetlands proposed by Semlitsch (2003) for maintaining local amphibian populations. A zone of 230 m may protect 95–100% of local pool-breeding salamanders (Faccio 2003) and the vast majority of *R. sylvatica*. A caveat is that even a conservation zone this large is conservative and assumes non-random distribution of animals; it will not necessarily provide linkages among other breeding pools needed for long-term survival of local populations. Highly fragmented landscapes that isolate ponds at distances greater than 1 km can preclude the recolonization of pools and result in the disappearance

Table 3. Seasonal pool-breeding amphibians and reported migration distances.

Indicator species	Maximum migration distance[1] (mean distance)	Number of studies contributing data
Ambystoma laterale	~198 m	3
Ambystoma jeffersonianum	625 m (198 m)	3
Ambystoma maculatum	249 m (129 m)	6
Ambystoma opacum	n/a	
Rana sylvatica	472 m	1
Scaphiopus holbrookii	n/a	

[1] Adapted from Calhoun and deMaynadier (2004).

of local populations in the landscape (Laan and Verboom 1990). Therefore, where landscapes are particularly pool-rich, preservation of large pool-upland complexes is recommended. Our goal is to minimize impacts to wildlife and to sustain viable populations within the context of a developing landscape. Specific recommended guidelines for common development activities that may threaten the integrity of any one of these zones are provided in Appendix 1.

Pool depression
This pool management zone includes the pool depression up to the spring high-water mark. The management goal for this zone is to maintain the pool basin, associated vegetation, and the pool water quality in an undisturbed state. Due to seasonal fluctuations in water levels, the pool depression may or may not be wet during the period when a development review is initiated. During the dry season, the high-water mark generally can be determined by the presence of blackened leaves stained by water or silt, aquatic debris along pool edges, water marks on surrounding trees or rocks, or a clear change in topography from the pool edge to the adjacent upland.

The pool provides breeding and nursery habitat for pool-breeding amphibians and invertebrates. Rutting or compaction of soil in the depression by vehicular equipment can alter pool hydrology, disturb eggs and larvae, and alter water quality through siltation or introduction of pollutants. Development in the pool depression in the winter may damage vegetation in the pool that potentially provides egg attachment sites and pool shade (Calhoun and deMaynadier 2004).

Pool envelope
The pool envelope extends 30 m from the pool's edge at spring high water. The management goals for this zone are: (1) to maintain shady, cool, moist forest floor conditions with abundant leaf litter and coarse woody debris through maintenance of a relatively undisturbed forest; (2) to allow free movement of amphibians to and from breeding pools; (3) to provide shade and leaf litter to the pool depression; and (4) to protect the water quality of the pool.

This zone is key terrestrial habitat for breeding amphibians and provides terrestrial nursery habitat for amphibian metamorphs. Adult *R. sylvatica* and *Ambystoma* spp. metamorphs exhibit significant non-random, directed dispersal orientation towards undisturbed forest versus clearcuts or other disturbances (Semitsch 1981; Windmiller 1996; deMaynadier and Hunter 1999; Rothermel and Semlitsch 2002; Vasconcelos and Calhoun 2004). In the spring, high densities of adult salamanders and frogs occupy the habitat within 30 m of the breeding pool (Regosin et al. 2003b; Vasconcelos and Calhoun 2004). Close proximity to pools may provide a selective advantage, enabling males to breed early and often. The same patterns were documented for *A. maculatum* (Regosin et al. 2003b). Metamorphs are particularly vulnerable to desiccation for the first 6 months after metamorphosis (Semlitsh 1981). In the late summer and early fall, large numbers of recently metamorphosed salamanders and frogs (Vasconcelos and Calhoun 2004) and male adult salamanders and frogs occupy this same area (Regosin et al. 2003b).

Critical terrestrial habitat
The critical terrestrial habitat extends ~200 m beyond the upland edge of the seasonal pool envelope (i.e., the zone 30–230 m beyond the edge of the pool depression). The management goals for this zone are to: (1) maintain or restore a minimum of 75% of the zone in relatively undisturbed forest as habitat for summer foraging and winter hibernacula; and (2) provide habitat though which animals may disperse to other pools for breeding or for summer refuge.

Limited data exist on summer home ranges and wintering areas of pool-breeding amphibians, but emergence data suggest that adults may travel hundreds of meters to other isolated pools, forested wetlands, small streams, or upland refugia where summer home ranges are established (Heatwole 1961; Bellis 1965; R. Baldwin, unpublished data; B. Windmiller, unpublished data). Holman et al. (2003) found that 40% of *R. sylvatica*, 52% of *A. laterale*, and 60 % of *A. maculatum* populations associated with three seasonal pools in Massachusetts overwintered greater than 100 m from breeding pools. A summary of management goals and recommendations for all 3 zones is presented in Table 4.

Table 4. Management recommendation for seasonal pools and surrounding management zones in developing landscapes.

Management Zone (distance from pool edge)	Area of Zone[1] (ha)	Primary Wildlife Habitat Values	Management Goals	Management Recommendations
Seasonal Pool Depression (n/a)	0.07	Breeding pool; egg attachment sites; larval development site.	Maintain good water quality and water-holding capacity; undisturbed basin with native vegetation along the margin	No disturbance
Seasonal Pool Envelope (30 m)	0.57	Shade and organic inputs to pool; upland staging habitat for juvenile amphibians.	Maintain forested envelope around pool; avoid barriers to amphibian movement; prevent alteration of water quality or pool hydrology.	No development; implementation of Recommended Guidelines (see Appendix 1) for this zone.
Critical Terrestrial Habitat (~230 m)	18.25	Upland habitat for pool-breeding amphibians (for foraging, migration, and hibernating).	Maintain partially shaded forest floor with deep, moist uncompacted litter and abundant coarse woody debris.	Less than 25% developed area; implementation of Recommended Guidelines (see Appendix 1) for this zone.

[1] Adapted area, based on a 30.5-m diameter pool.

Conclusions

Strategies or BDPs for conserving seasonal forest pools within urbanizing landscapes are based on the best available science. Further research should be conducted to develop and refine our understanding of seasonal pool resources and the effects of land use practices on those resources. In the interim, it is imperative that currently available research results, albeit incomplete, be translated into tools that can be applied by land use decision-makers. A mechanism for revisions based on later research developments should be part of the overall planning process. Seasonal forest pools and many other habitats are rapidly being destroyed or altered as sprawl overtakes formerly rural regions. If we, as conservation scientists, do not create tools such as best development practices, then they will continue to be crafted, but without a biological perspective. If we mistakenly choose not to sit at the table, we should be aware that the banquet will continue without us.

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Appendix 1

(Adapted from Calhoun and Klemens 2002). Recommended guidelines for development activities near seasonal woodland pools.

Roads and driveways

1. Roads and driveways should be excluded from the pool depression and pool envelope.
2. Roads and driveways with projected traffic volumes in excess of 5–10 cars per hour should not be sited within ~230 m of a seasonal pool (Windmiller 1996). Regardless of traffic volumes, the total length of roads within the critical terrestrial habitat should be limited to the greatest extent possible (Egan and Paton, 2004).
3. Use curbing with a 1:4 slope that small animals can cross (Cape Cod-style curbing) or no-curb alternatives on low capacity roads.
4. Use oversize square box culverts (2 × 3 ft) near wetlands and known amphibian migration routes to facilitate amphibian movement under roads. These should be spaced at 6-m intervals *and* use curbing to deflect amphibians toward the box culverts.
5. Use cantilevered roadways (i.e., elevated roads that maximize light and space underneath) to cross low areas, streams, and ravines that may be important amphibian migratory routes.
6. Cluster development to reduce the amount of roadway needed and place housing as far from vernal pools as possible.

Site clearing, grading, and construction activities

1. Minimize disturbance and protect existing buffer areas to the extent practicable.
2. Site clearing, grading, and construction activities should be excluded from the pool depression *and* the pool envelope.
3. Site clearing, grading, and construction activities should be limited to less than 25% of the entire pool habitat (i.e., the pool depression, envelope, and critical terrestrial habitat).
4. Limit the area of clearing, grading, and construction by clustering development.
5. Minimize erosion by maintaining vegetation cover on steep slopes.
6. Avoid creating ruts and other artificial depressions that hold water. If ruts are created, refill to grade before leaving the site.
7. Refill percolator test holes to grade.
8. Use erosion and sediment control best management practices to reduce erosion. Stagger silt fencing with 6-m breaks to avoid disrupting amphibian movements or consider using erosion control berms. Use combinations of silt fencing and hay bales to reduce barrier effects. Re-seed and stabilize disturbed areas immediately; permanent stabilization for revegetated areas means that each area maintains at least 85% cover. Remove silt fencing as quickly as possible and no later than 30 days following final stabilization. Minimize use of silt fencing within ~230 m of pools. Erosion control berms can be leveled and used as mulch or removed upon final stabilization.
9. Limit forest clearing on individual house lots within the developed sections of the pool management zones to no more than 50% of lots that are 0.8 ha or more in size. Encourage landscaping with natural woodland, containing native understory and groundlayer vegetation, as opposed to lawn.
10. Silt fencing *should* be used to exclude amphibians from active construction areas. However, construction activities should, ideally, occur outside of peak amphibian movement periods for the amphibian species occurring in your region (which include early spring and fall breeding and mid-late summer dispersal).

Stormwater management

1. Pool depressions should never be used, either temporarily or permanently, for stormwater detention or biofiltration.
2. Detention and biofiltration ponds should be located at least 230 m from a pool; they should never be sited between pools or in areas that are primary amphibian overland migration routes, if known.
3. Treat stormwater runoff using grassy swales with less than 1:4 sloping edges. If curbing is required, use Cape Cod curbing. Maximize open drainage treatment of stormwater.
4. Use hydrodynamic separators only in conjunction with Cape Cod curbing or swales to avoid funneling amphibians into treatment chambers, where they are killed.
5. Maintain inputs to the vernal pool watershed at pre-construction levels. Avoid causing increases or decreases in water levels.
6. Minimize impervious surfaces (i.e., surfaces that do not absorb water) to reduce runoff prob-

lems and resulting stormwater management needs. Use of grass pavers (concrete or stone that allows grass to grow) on emergency access roads and in low use parking areas is recommended. Use of phantom parking is also recommended. Zoning formulae often require more parking spaces than are actually needed. Under a phantom parking strategy, sufficient land is reserved for projected parking requirements, but only a portion of the parking area is constructed at the outset. Additional areas are paved on an as-needed basis.

7. Examine the feasibility (which varies by location) of reducing the road width standard to achieve conservation goals (i.e., minimize the footprints of roads). This is often done in tandem with development clustering, to reduce impervious surfaces and disturbance areas.

Lighting

1. Exterior and road lighting within 230 m of a pool should use low spillage lights – those that reflect light directly downward onto the area to be illuminated. A variety of products to accomplish this goal are now on the market. Avoid using fluorescent and mercury vapor lighting.

Wetland creation and alteration

1. Alteration of natural conditions within seasonal forest pools and other small wetlands should be avoided.
2. Creation of ponds and similar wetlands should be avoided within 230 m of a pool.
3. Redirect efforts from *creating* low-value, generalized wetlands to *enhancing* terrestrial habitat around pools. These enhancements could include reforestation of post-agricultural lands within 230 m of a pool, restoration of forest, importing additional cover objects (e.g., logs, stumps), and removal of invasive plants and animals.

Post-construction activities

1. Discourage predators by making garbage and other supplemental food sources unavailable.
2. Consider keeping cats indoors at all times. This would reduce depredation on a wide variety of species, ranging from pool-breeding amphibians to ground-nesting birds. Attaching bells to cat collars does not significantly reduce the ability of cats to prey on small vertebrates.
3. Mark the edge of a protected area (e.g., the critical terrestrial habitat) with permanent markers. Well-marked boundaries make enforcement of restricted areas clear to both homeowners and the local wetlands enforcement agencies. For example, granite monuments or stone cairns could be placed every 3 m around a protected area. In cases where intrusion is a concern, small sections of stonewall could be erected; these walls should be discontinuous, so that they do not impede amphibian movements.
4. Use covenants or deed restrictions to assure that the vernal pool and its envelope are conserved and that pesticide use, lot clearing, and other degrading activities are kept out of associated areas. Assign the homeowner or homeowner's association with responsibility for ensuring that conditions of the covenant or deed restriction are met. Provisions should also be included to allow a third party, such as the town or local land trust, to enter the property with adequate notice, and conduct appropriate management and remediation, charging the homeowner for these services.
5. In the case of a homeowner's association or other type of multiple tenant arrangement, a stewardship manual could be prepared that would educate each purchaser, or lessee, as to the unique nature of the property they are purchasing or renting, what their collective obligations to protect the resource entail, and where to obtain additional assistance or information.
6. A conservation easement, covering at minimum the vernal pool depression and vernal pool envelope (and, preferably, including land within the 'critical terrestrial habitat'), could be held by a municipality, land trust, or other non-governmental organization.

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