Temporary wetlands: challenges and solutions to conserving a 'disappearing' ecosystem

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Temporary wetlands: challenges and solutions to conserving a 'disappearing' ecosystem

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ABSTRACT

Frequent drying of ponded water, and support of unique, highly specialized assemblages of often rare species, characterize temporary wetlands, such as vernal pools, gilgais, and prairie potholes. As small aquatic features embedded in a terrestrial landscape, temporary wetlands enhance biodiversity and provide aesthetic, biogeochemical, and hydrologic functions. Challenges to conserving temporary wetlands include the need to: (1) integrate freshwater and terrestrial biodiversity priorities; (2) conserve entire 'pondscapes' defined by connections to other aquatic and terrestrial systems; (3) maintain natural heterogeneity in environmental gradients across and within wetlands, especially gradients in hydroperiod; (4) address economic impact on landowners and developers; (5) act without complete inventories of these wetlands; and (6) work within limited or non-existent regulatory protections. Because temporary wetlands function as integral landscape components, not singly as isolated entities, their cumulative loss is ecologically detrimental yet not currently part of the conservation calculus. We highlight approaches that use strategies for conserving temporary wetlands in increasingly human-dominated landscapes that integrate top-down management and bottom-up collaborative approaches. Diverse conservation activities (including education, inventory, protection, sustainable management, and restoration) that reduce landowner and manager costs while achieving desired ecological objectives will have the greatest probability of success in meeting conservation goals.

1. What are temporary wetlands?

Intermittently inundated wetlands, known as temporary wetlands, are generally shallow, small, aquatic features found in a variety of landscape settings. Temporary wetlands vary greatly in their predominant water sources and outflows, and in all cases are connected to other aquatic features through atmospheric connections inherent to the water cycle (Mushet et al., 2014). Their key defining feature is that they often dry annually or unpredictably to the point that they lack ponded surface water.

The drying of temporary wetlands results in shorter hydroperiods (i.e., the length of time water is ponded and frequency of flooding) relative to permanent aquatic systems. Hydroperiod is the main driver of communities and population dynamics (Boix and Batzer, 2016) and leads to these wetlands often supporting unique biotic communities (Wiggins et al., 1980; Williams, 1985). Examples of small temporary wetlands include cypress domes, vernal pools, bays, prairie potholes, playas, athalossohaline (saline endorheic) wetlands, springsoaks, gilgais, ponds from lowland to alpine environments, Mediterranean ponds, turloughs and rock pools; and, although they are mainly small in size, globally they cover a greater total area than lakes (Fig. 1; Downing et al., 2006).

2. Why are these features important, both ecologically and economically?

Temporary wetlands encompass a diverse array of Small Natural Features (SNFs), saline and fresh, in a variety of landscape settings.

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Fig. 1. Examples of temporary wetlands (clockwise from top left): Gilgais amongst Plains Grassy Woodland, Monea North Nature Conservation Reserve, Victoria, Australia (photo: J. Fitzsimons); Alpine seasonal pools, Val Thorens, alt. 2520 m, French Alps (photo: F. Isselin); Great Plains prairie pothole, North Dakota, USA (photo: D. Mushet); small rock pool, Massif Central alt. 1500m, Parc Naturel Régional des Volcans d'Auvergne, France (photo: F. Isselin); dry vernal pool, Acadia National Park, Maine, USA (photo: A. Calhoun); Mediterranean temporary pond, Alberta piedmont, Catalonia, Spain (Photo: A. Ruhí).

Small Natural Features, much like keystone species (but at an ecosystem scale), are disproportionately important in their role within entire landscapes than would be assumed by their small size (e.g., bat caves, large old trees, see Hunter, 2017–in this issue). In the case of temporary wetlands, their importance is both belied and enhanced by their ephemeral hydroperiod in addition to their small size. The diversity of temporary wetlands provides a continuum of functions and ecosystem services from the wetland depression to much larger spatial scales.

We provide detail on how temporary wetlands function as SNFs and as such, share many conservation challenges and solutions with other SNFs (see Hunter et al., 2017–in this issue).

2.1. Hydrology and biogeochemistry

Temporary wetlands and other small water bodies provide disproportionate contributions to hydrologic and biogeochemical functions than would be predicted by their proportional area in any given watershed and, in toto, play a major role in global cycles (Downing, 2010). Rains et al. (2016) described the central hydrologic importance of temporary wetlands at the landscape scale as "nodes in hydrologic networks connecting landscapes in four dimensions—longitudinal, lateral, vertical, and through time". Networks of temporary wetlands exist along a continuum of hydrologic connectivity from relative hydrologic isolation to predicted connectivity (Leibowitz et al., 2008; McLaughlin et al., 2014) (Fig. 2). Depending on landscape position, they are important for reducing peak floodwater flows, contributing to groundwater recharge or discharge (Euliss et al., 2004; Ganesan et al., 2016), and providing stream base flow. Temporary wetlands also provide lag, sink, and source (contribution) functions (as summarized by Rains et al., 2016) and "spill and fill" and "spill and merge" functions (Leibowitz et al., 2016) that have effects on the physical, chemical, and biological status of downstream waters.

Biogeochemical functions, largely driven by the varied hydrologic regimes that characterize temporary wetlands, include carbon sequestration (Holgerson, 2015), denitrification, sediment retention, pesticide transformation (Zeng and Arnold, 2013), and absorption of phosphorus and other aquatic pollutants. Marton et al. (2015) have shown that, like temporary streams, these wetlands have disproportionately large reactive perimeters relative to their area and are more reactive per unit area than other wetlands or adjacent upland soils, since it is the wetland edge where biogeochemical and other wetland functions tend to be enhanced (Cohen et al., 2016). Capps et al. (2014) found that vernal pools in central Maine, USA, function as hotspots of leaf litter decomposition, denitrification and enzyme activity compared to adjacent upland forest sites. While such estimates and attempts to scale-up to capture regional contributions of temporary wetlands are coarse, current data suggest temporary wetlands may play a significant role in hydrologic and biogeochemical processes beyond the pool itself.

2.2. Biodiversity

Temporary wetlands increase biodiversity at within-pool to landscape scales through the addition of an aquatic feature (ephemeral to semi-permanent) in a terrestrial matrix that otherwise would include only permanent aquatic features, if any. By supporting biota adapted to living in temporary waters, these wetlands contribute disproportionately to the diversity of both aquatic and facultative animals and plants (Herault and Thoen, 2009; Pinto-Cruz et al., 2009). In France, for example, vernal pools represent 0.05% of the natural habitats but hold around 35% of rare species (some are endangered at the European level) and 5% of the protected plant species (Sajaloli and Limoges, 2001). Moreover, obligate temporary species (i.e., some branchiopods) are examples of extremely rare species only known from selected ponds around the world (Alonso and García-de-Lomas, 2009; Cottarelli et al., 2010).

Temporary wetlands serve as aquatic stepping stones in an upland matrix and provide foraging and resting habitat for facultative species migrating to other resources. For example, the agile frog (*Rana dalmatina*) in Europe can breed in different temporary ponds depending on the year (Guyetant, 1997) and the northern leopard frog (*Lithobates pipiens*) and bullfrog (*Lithobates catesbeiana*) in the USA overwinter in deep-water habitats, migrate to temporary wetlands for reproduction or feeding, and then return to deep-water habitats to hibernate (Mushet et al., 2013). Many terrestrial mammals, non-breeding amphibians, reptiles, and birds, use the abundant carbon resources in pools (i.e., egg masses, amphibian larvae and adults, invertebrates, algae and plants) to supplement their diets, especially following winter in temperate and boreal regions (Paton, 2005).

2.3. Socioeconomic

Temporary wetlands provide valuable ecosystem services including wildlife habitat, nutrient flux to adjacent ecosystems, flood control, water filtration, and cultural services (e.g., Turner et al., 2008; Gascoigne et al., 2011; TSSC, 2012). The social importance of these features follows from the ecological importance of temporary wetlands enumerated above. For example, some wetlands, such as soaks associated with rocky outcrops, gnamma holes and gilgais, were an important source of water for indigenous communities as they enabled people to seasonally forage over areas that lacked permanent water (see Fitzsimons and Michael, 2017–in this issue). Gilgais have also been

Fig. 2. Various forms/strengths of surface-water connections are visible in this aerial photograph of a prairie pothole wetland complex in Stutsman County, North Dakota, U.S.A. (Photo: D. Mushet).

used by grazers to seasonally graze stock in areas that lacked permanent water (Lachlan Riverine Working Group, 2016). Prairie potholes provide breeding habitat for over 50% of all North American duck populations despite covering only a tiny portion of the area of their range (Baldassarre and Bolen, 2006). These habitats may also support recreational and educational opportunities globally. For example, large dry lake beds in arid and semi-arid regions are often tourist destinations visited as natural wonders (e.g., Chott el Djerid in Tunisia famous as a filming venue for Stars Wars). Additionally, scientific advances documenting the range of functions provided by temporary wetlands enhance our understanding of their social importance (see Bauer et al., 2017–in this issue).

3. What are the current threats and management challenges?

3.1. Inadequate regulations

The lack of rigor and consistency in regulatory protections for small aquatic resources is a global phenomenon (see Acuña et al., 2017–in this issue). For example, the European Water Framework Directive does not apply to water bodies and wetlands of less than 50 ha. In France, modifications of water bodies, permanent and temporary, of less than 0.1 ha do not need to be reported. Similarly, existing Federal regulations in the US (Clean Water Act and Food, Conservation, and Energy Act of 2008) more thoroughly regulate larger wetlands (Mushet et al., 2014). In addition, wetland regulations typically target the wetland depression with little regard to adjacent terrestrial ecosystems or connectivity to other critical wetland resources (Cohen et al., 2016). Some small aquatic resources do receive enhanced protections but such protections are afforded to a small subset of the resources. For example, Mediterranean temporary ponds (MTPs) are a priority habitat according to the Natura 2000 network of the European Union and special protections apply in a number of Mediterranean countries (Bagella et al., 2007; Zacharias and Zamparas, 2010). In the US, some states provide enhanced protections for special aquatic resources such as vernal pools (Mushet et al., 2014). Until recently, research on temporary wetland functions has been sparse, especially with respect to their landscape-scale functions (but see Holgerson, 2015; Golden et al., 2016). The cumulative, landscape scale impacts of loss of small wetlands are not currently addressed in regulatory frameworks.

3.2. Direct modification to temporary wetlands and changes in land use

Temporary wetlands are threatened by human population growth and the resultant ecosystem loss and degradation from urbanization, agriculture, livestock (switching temporary wetlands to permanent pools; Beja and Alcazar, 2003; Euliss and Mushet, 2004), water extraction, and other human-mediated impacts to biodiversity, including sedimentation (Grillas et al., 2004) and presence of toxic pollutants (Collins et al., 2014). However, because they are small and often indistinguishable from uplands in their dry phases, they are vulnerable to loss or degradation even by relatively minor disturbances (Boix et al., 2016). For example, many prairie potholes (60–65%) have been drained to facilitate crop production and the soils of remaining temporary wetlands are often tilled and planted after they dry (Dahl, 2014) or pools are consolidated increasing the hydroperiod (Anteau, 2012). Similarly, in southern Australia, from the mid-1990s to present, increased profitability of cropping over previously grazed lands allowed the cultivation of previously unprofitable areas, including wetlands. The ephemeral nature or 'disappearing' feature of these temporary ponds leads to clearance or filling of wetlands as landowners may be unaware that they are clearing a wetland (TSSC, 2012). Losses of gilgais in stony deserts from grazing (Smyth et al., 2007) to losses of alpine temporary wetlands to snow making in ski resorts (Gaucherand and Isselin-Nondedeu, 2011), are just a few examples of land-use changes threatening small wetlands.

3.3. Climate change

Temporary wetlands, by virtue of their small size (high watershed to surface area or volume ratio) and temporary hydroperiods, are very responsive to changes in temperature and precipitation patterns. The International Panel on Climate Change's predictions for the next 100 years suggest that temperature increases will be greatest in high latitudes, precipitation amounts and patterns will change, extreme storm events will increase, and sea levels will rise 20–60 cm (Junk et al., 2013). Responses to climate change will vary across a gradient from arid to boreal regions, from individual wetlands and types, and across species. For example, temporary ponds and their biota in Mediterranean climates are more threatened by reduced precipitation, increased salinity, and extended droughts than temperate or boreal temporary wetlands. Precipitation events may become more extreme in some areas coupled with seasonal changes in distribution (Junk et al., 2013). Extreme shifts in aquatic invertebrate diversity (Sim et al., 2013; Renton et al., 2015) and plant species composition (Ghosn et al., 2010; Bagella and Carmela Caria, 2013) may occur in all temporary systems (wetlands and waterways).

3.4. Invasive species

In every continent, invasive species are a major threat to wetland biodiversity (Brinson and Malvarez, 2002; Zedler, 2004). Although the period of time without water impedes the colonization by exotic fishes, many exotic and specially adapted species have invaded temporary waters, including plants (Collinge et al., 2011; TSSC, 2012; Brundu, 2015), crayfishes (Carreira et al., 2014; Rodriguez-Perez et al., 2014), and amphibians (Escoriza et al., 2014; Meilink et al., 2015). These invaders have contributed to the loss of species, wetland functions, food web dynamics, and habitat structure.

Although any of these threats can be significant in their own right, the interactions of changing climate, invasive species, and increasing social demands for food, space, and water resources makes clear proactive management strategies essential if we are to meet our conservation goals (Rahel and Olden, 2008; Zacharias and Zamparas, 2010).

3.5. Management challenges

3.5.1. Ecological

Temporary wetlands require management at local and landscape scales; they are active biological, physicochemical, and ecological nodes in a terrestrial matrix (Mushet et al., 2014). Since temporary wetlands are defined by hydroperiod, they are extremely susceptible to changes in land-use patterns and activities *beyond* the wetland footprint that alter hydrologic patterns. Because most temporary wetlands have high perimeter to surface area ratios and relative low volume with limited inlet and outlets, if present at all, they are also quite sensitive to alteration in chemistry from sediments and pollutants. In addition, many temporary wetlands support wildlife with biphasic or complex life histories involving annual migrations of hundreds of meters, making the adjacent terrestrial habitat an integral part of conserving their functions (Semlitsch, 2002; Groff et al. 2016). Direct losses or fragmentation of wetlands, particularly ephemeral ponds, decreases wetland density increasing travel distances for biota, particularly those organized in metapopulations, using multiple aquatic resources (Gibbs, 1993). Conservation of temporary wetlands and specialists that depend on these habitats is made difficult by trends in conservation priorities, funding, and research that discount these resources (Martín-López et al., 2011) and therefore undercut scientific understanding of multi-scale processes. One major challenge is then to manage, conserve, or restore by integrating several spatial scales, from wetland to landscape scales, taking into account all fluxes of energy, materials and organisms. Clearly, one will not be able to manage for all things, but being aware of the implications of management is important at any scale.

3.5.2. Social

Limited public awareness and understanding and incomplete inventories of temporary wetlands complicates management of these natural features. For many temporary wetlands, public understanding of their functions, and the value of non-game, pond-associated wildlife, is limited, diminishing support for public conservation actions (Marton et al., 2015; Mushet et al., 2014; Cohen et al., 2016). Temporary wetlands generally lack a charismatic flagship species to capture the hearts and minds of the public (but large branchipods or amphibians may be good candidates if marketed well) and can be considered mosquito breeding havens. Nonetheless, society generally values a range of features that may be associated with temporary wetlands including rarity of the habitat type, endemic or threatened species, or a good example of a wetland type embedded in wild areas (see Wilcove and Ghazoul, 2015).

Their small size, ephemeral nature, limited formal protection, and wide spatial distribution make them seem common and problematic especially to individual landowners who can envision a "better" use of land. One notable exception is the prairie pothole region where the importance of temporary wetlands in supporting breeding waterfowl has been widely recognized and led to the region becoming known as the "duck factory of North America" (Lynch, 1984; Batt et al., 1989). Less visible ecosystem functions however, such as biogeochemical and stream base flow support, are often not easily appreciated or valued (Millenium Ecosystem Assessment, 2005). Numerous naturalist associations and scientific networks are active in developing outreach and inventory tools (e.g., Million Ponds Project in UK [http://freshwaterhabitats.org.uk/]; the network for pond conservation and information in France [http://pole-zhi.org], Portugal [http://www.charcoscomvida.org/], and vernal pools in northeastern USA [http://vernalpools.me]).

Ecosystem services of temporary wetlands will have to be better quantified and explained to change perceptions of value and management structures. The spatial mismatch between conservation benefits and costs can challenge conservation of temporary wetlands. For example, widespread benefits from conservation but concentrated costs of conservation (Brown and Shogren, 1998; Shogren et al., 2003) complicate strategies based on negotiations with individual landowners who have wetlands on their properties. While the social importance of temporary wetlands can be quite significant (because they are the summation of many values held by society), temporary wetlands may offer individual landowners (such as producers, developers, or single family private landowners) only limited private value relative to competing uses of lands. Restriction on private property uses can become a significant issue in areas where temporary wetlands are regulated (Jansujwicz et al., 2013a; Levesque et al., 2016). Management approaches that recognize the spatial distribution of benefits and costs and full extent of conservation costs are more likely to navigate these challenges successfully (Shogren et al., 2003; Bauer et al., 2010; Sunding and Terhorst, 2014).

4. Activities and approaches to conserving temporary wetlands

Small natural features, by virtue of their size, may be more difficult or expensive to comprehensively inventory, and hence manage, than more imposing natural features such as lakes, rivers, or grasslands. For temporary wetlands, this challenge is compounded by their ephemeral nature (i.e., the disappearing resource) which can be considered in both the physical and conceptual realms (as these wetlands are often "ephemeral" in the minds of practitioners and the public, i.e., out of sight, out of mind). Developing innovative approaches for conservation of these resources is paramount. We explore six conservation actions that in combination or as parallel efforts may ensure the long-term persistence of temporary wetlands in developing landscapes: educate, inventory, protect, sustainably manage, and, as a last resort or complement to other actions, restore and create. We also include an approach on collaborative conservation, which we believe can naturally evolve from the previous actions. Following Hunter (2017–in this issue), we recognize four different approaches to management – incidental, voluntary, incentive-based, and restrictive – provide a wide foundation for such activities.

4.1. Educate

For temporary wetlands, education is a critical first step. Temporary wetlands often provide functions not easily embraced by the public including broader water quality functions and support of biodiversity at landscape or regional scales. The goal of successful education is to have the word "playa" or "temporary pond" or "gilgais" in the lexicon of the average citizen *and* to have the term associated with at least one positive attribute (e.g., duck habitat or the sound of chorusing frogs in the spring).

Human perceptions of temporary wetlands vary with time and context (Brock, 2009). For example, temporary wetlands are seen as a water resource in fisher-hunter-gatherer societies, a water supply for livestock and humans in agriculture societies, or as land to reclaim in some urbanized settings. For some temporary wetlands, such as North American prairie potholes, their fame as the "duck factory of North America" (Lynch, 1984) may support conservation efforts through public interest of game species as compared to wetlands with less charismatic species such as wood frogs. Improving public awareness of the values of temporary wetlands is an important outreach goal which may result in stronger protections (Angeler, 2009; Brock, 2009).

Translation of science into policy, or knowledge to action, remains a challenge for both scientists and practitioners (Moss et al., 2009; Hall and Fleishman, 2010), so making scientific findings accessible to regulators, resource managers and lay people is a logical first step. For example, educational outreach has helped to reverse some forestry practices detrimental to temporary ponds in the region of Chinon in France where it has been estimated that 90% of temporary wetlands were destroyed after intensive tree plantation and drainage (Couderc, 1979; Isselin-Nondedeu et al., 2013). In the northeastern United States, 15 years of development and dissemination of educational resources on vernal pools were needed before the regulators, resource managers and the public could be engaged in effective regulatory and voluntary protections of vernal pools (Jansujwicz et al., 2013a; Calhoun et al., 2014a). This substantial investment in education generated the support in this region that underpins the strongest vernal pool regulatory framework in North America (Mahaney and Klemens, 2008; McGreavy et al., 2016).

4.2. Inventory

To effectively manage temporary wetlands individually and on a landscape scale, it is essential to have a spatially explicit inventory (notably whether they occur singly or in complexes, patchily or evenly distributed) and an assessment of their ecological status, including the adjacent terrestrial matrix (Van Meter et al., 2008; Van den Broeck et al., 2015). For example, remote sensing studies conducted in several Mediterranean regions (e.g., De Roeck et al., 2008; Rhazi et al., 2012) have documented the disappearance and degradation of temporary ponds. Still, detailed wetland inventories are lacking in large sections of the world (e.g., China, South America, Russia), and, small wetlands are often disregarded or not captured in places where inventories are conducted (Robertson and Fitzsimons, 2004; Junk et al., 2013). In addition, information may be available but poorly accessible and dispersed across agencies or private entities. If wetlands are mapped remotely, the ability to identify these features will vary greatly depending on the nature of the matrix. For example, in forested landscapes containing vernal pools in midwestern and northeastern North America remote detection is problematic, often missing as much as 30% of pools (Tiner et al., 2015; Dibello et al., 2016). Even in open areas, remote detection of small wetland features can be limited by atmospheric conditions or spatial resolution of the sensor being used (Rover and Mushet, 2015). However, as technologies continue to improve (e.g., Wu and Lane, 2016), the ability to remotely detect and map small wetland features will continue to improve, especially with 3-D digital technology and high resolution LiDAR (Tiner et al., 2015; Wu and Lane, 2016).

Despite these general constraints, historical reviews, inventory, and assessment projects can be developed at multiple scales from local, low-cost, voluntary programs using citizen scientists to inventory and map temporary pools as has been done in Maine, USA, (see Jeffries, 2012; Jansujwicz et al., 2013b) to major regional inventory and assessments associated with research, consulting projects, or government initiatives (Lathrop et al., 2005).

4.3. Protect

Management of temporary wetlands in the form of regulations may range from restrictive local protections conserving vernal pools and tens of meters of adjacent habitat to broader national regulations (e.g., the listing of the 'Seasonal Herbaceous Wetlands [Freshwater] of the Temperate Lowland Plains' ecological community as critically endangered under national threatened species/communities legislation in Australia). Top-down regulation (at any government level) has the advantage of setting clear rules, but may suffer from lack of enforcement or "buy in" from the stakeholders being regulated. This is particularly true for smaller ecological features, such as temporary wetlands that are more likely to fall on private property. Hence, conservation may best be achieved using both top-down approaches to set a standard to be emulated and complemented by more tailored, local or voluntary approaches that can afford stronger protections (Calhoun et al., 2014a). For example, vernal pool regulations from Federal or State levels may only protect the pool footprint and a small buffer around the pool; local regulations may be written to conserve more of the post-breeding habitat.

Protection may also result from crisis management of increasing threatened or rare temporary wetlands. For example, in southeastern Australia, ephemeral wetlands such as gilgais typically occur on fertile country which was privatized and suffered from conversion to more intensive agricultural activities. As such, there has been a significant reduction in the extent of these systems and protection of what remains is still limited. Efforts to increase the representativeness of Australia's reserve system has seen the acquisition of a number of significant properties containing temporary wetlands (e.g., Fitzsimons and Ashe, 2003; Fitzsimons et al., 2004). This sort of protection afforded through conservation of publicly owned parks or easements on large parcels of private lands may present the best opportunities for public education as well (walks to temporary ponds, boardwalks and informational signage).

4.4. Sustainably manage

Small natural features, including temporary wetlands, are arguably best managed using the meso-filter approach (Hunter, 2005), where features that may be small ecosystems in their own right or ecological elements within larger ecosystems can, by nature of their small size, open the door to sustainable management. Management approaches (including landowner incentives) will range from practices specific to land uses adjacent to temporary wetlands (e.g., voluntary best management practices for forest operations or development) to landscape-scale approaches that recognize the functions of temporary wetlands as wetland complexes embedded in, and likely integral to, other ecosystems. For example, in arid and semi-arid Australian rangelands, gilgai conservation was considered a key feature in market-based incentives for landholders to better manage grazing (Smyth et al., 2007). In southeastern Australia, market-based auctions for conservation actions have been in place for the past decade and would prioritize ephemeral wetland communities due to their conservation status based on past loss and ongoing threats. Integration of vernal pools as a component of forest biodiversity is a way to manage sustainably both terrestrial and aquatic habitats. In many national forests in France and commercial forests in the northeastern US, the application of best management procedures includes reducing disturbance immediately adjacent to pools by implementation of management zones around the pools and implementing standards for maintaining uneven aged forest stands (Calhoun and de Maynadier, 2004; Guittet et al., 2015).

Best management practices for forestry and for development around temporary wetlands and adjacent uplands can lead to management practices that support the array of wetland functions that are integrated with contiguous terrestrial ecosystems (Calhoun and Klemens, 2002). This approach may work in some sectors (for example, in the commercial forestry community where harvesting practices can be modified and no-cut zones established) or where temporary wetland protections do not seriously impede economic development. Adoption of best management practices may be used to enhance the public image of the manager, e.g., "green" forestry or "green" development and may meet environmental outreach and education goals.

Sustainable management in the face of climate change necessitates approaches that, as Beier et al. (2015) recommend, conserve "nature's stage". This approach moves conservation away from focusing on dynamic targets such as community types, e.g., spruce-fir forests or wood frog breeding pools, to capturing the physical features that support the array of defining characteristics of any given ecosystem target. For temporary wetlands, this would mean conserving an array of hydrogeomorphic settings (ones that support short to long hydroperiods in different physical settings) allowing a range of biogeochemical and water quality functions as well as support of diverse biota (Marton et al., 2015); this approach increases chances that species and processes can evolve with changes in climate. In addition, the importance of allowing for gene flow among diverse temporary pool communities is highlighted by Rice and Emery (2003) and others who advocate for maintaining or restoring microevolutionary processes to meet the challenges of a shifting climate.

When demands for monies to conserve natural resources are high and resources are diminishing, it is essential to develop partnerships with other conservation entities or identify unique opportunities for meeting disparate goals with desirable outcomes for both parties (Jansujwicz and Calhoun, 2010; Paulich, 2010; Levesque et al., 2016). In the northeastern US, for example, mitigation dollars for vernal pool impacts can be combined with dollars from NGOs to target pool complexes in rural settings. An entrepreneurial developer in New England, USA, is investigating developing a business purchasing exemplary vernal poolscapes (pool and pool complexes with suitable terrestrial habitat for pool-breeding amphibians) to serve as a pool mitigation bank for developers. This benefits developers and the conservation community by pre-identifying and securing poolscapes in a rapidly developing region of the US and provides developers with ready-made mitigation opportunities.

4.5. Restore or create

Restoration or creation of temporary wetlands may result from legal restrictions on impacts that require mitigation for these losses or from voluntary efforts to ameliorate losses. An inability to recreate hydrology is often the cause of a failure in restoring or creating temporary wetlands, particularly for pool-breeding amphibians and invertebrates (Petranka et al., 2007; Calhoun et al., 2014b; Drayer and Richter, 2016). In the North American prairie pothole region, efforts to restore plant communities of temporary wetlands typically result in communities of lower floristic quality compared to plant communities of undisturbed wetlands (Mushet et al., 2001), but successes in plant restoration have been reported in other regions of the USA (Ferren and Hubbard, 1998). In addition, landscape setting and condition and location with respect to other aquatic resources is important to wetland functions. It will be hard to recreate this in off-site creation projects. In some situations where losses are very high, restoration or creation may be a good option. For example, restoration of vernal pools in France and Spain have attempted to create short hydroperiods by digging shallow pools that are very dependent on precipitation. Initial results concerning abiotic functions and amphibian colonization are promising (Ruhí et al., 2012; Isselin-Nondedeu et al., 2013). However, even after relatively long periods post restoration, communities and ecological functions in many temporary wetlands are often not entirely restored (Ruhí et al., 2009; Matthews and Spyreas, 2010; Moreno-Mateos et al., 2012; Ruhí et al., 2016). Creating temporary wetlands where they previously did not exist is an even greater challenge.

4.6. Collaborative conservation

Temporary ponds are often on private property and may not be regulated. A creative hybrid approach–a community based collaborative effort that draws from both top-down (if it exists) and bottom-up regulatory restrictions–may be a very effective conservation tool (Freeman et al., 2012; Calhoun et al., 2014a; Levesque et al., 2016). An incentive-based approach for conserving vernal pools in New England, USA, was developed through a collaboration among Federal, State, and local governments, in consultation with ecologists, the development community, environmental nongovernmental organizations, and land trusts to develop an alternative mitigation tool for vernal pool losses. This tool is a local in lieu fee program where developers may impact wetlands in municipal areas zoned for development in return for a fee collected to incentivize local landowners to conserve temporary wetlands in designated rural zones (Special Area Management Plan for Vernal Pools in US Army Corps of Engineers Region 1; Levesque et al., 2016). This innovative approach improves Federal regulations by tailoring the conservation to local needs that support both conservation and economic development. In this case, discontent with the top-down "stick" of government restrictions that assume one-size-fits-all served as momentum for creativity and more local control.

Collaborative approaches of a more voluntary nature may evolve without the regulatory "stick". For example, in Australia, collaborative landscape-scale arrangements such as Conservation Management Networks (biophysical networks of remnant vegetation sites across a variety of tenures and a social network of managers, owners, and interested people) have also been applied in fragmented landscapes containing temporary wetlands (Edwards and Fox, 2013; Fitzsimons et al., 2013). These arrangements seek to (a) increase the protection status of sites; (b) maintain, enhance and re-establish remnants across private and public land; (c) bring together owners and managers of vegetation remnants; (d) connect and buffer remnant patches; and (e) develop consistent and complementary management across sites, and are across tenures.

5. Conclusion

The biodiversity, hydrological and biogeochemical functioning of temporary wetlands that support ecosystem services, and their important social value in different countries, make these small natural features of considerable interest to practitioners and scientists alike. Meso-filter approaches focus on conserving small natural features in a human-dominated landscapes at a scale that engages landowners while effecting conservation at scales relevant to supporting ecosystem processes. Restoring a single temporary wetland in a degraded surrounding environment is often irrelevant and ineffective. A holistic approach to developing flexible conservation strategies will have the greatest probability of success in maintaining more fully functioning landscapes.

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