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Review Article

A Place to Call Home: Amphibian Use of Created and Restored Wetlands

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Loss and degradation of wetland habitats are major contributing factors to the global decline of amphibians. Creation and restoration of wetlands could be a valuable tool for increasing local amphibian species richness and abundance. We synthesized the peer-reviewed literature addressing amphibian use of created and restored wetlands, focusing on aquatic habitat, upland habitat, and wetland connectivity and configuration. Amphibian species richness or abundance at created and restored wetlands was either similar to or greater than reference wetlands in 89% of studies. Use of created and restored wetlands by individual species was driven by aquatic and terrestrial habitat preferences, as well as ability to disperse from source wetlands. We conclude that creating and restoring wetlands can be valuable tools for amphibian conservation. However, the ecological needs and preferences of target species must be considered to maximize the potential for successful colonization and long-term persistence.

1. Amphibian Habitat Loss and Restoration

1.1. Amphibian Decline. It is widely accepted that amphibians are experiencing world-wide declines in abundance and diversity (e.g., [1–5]). Stuart et al. [6] estimated more than 2400 of the approximately 5700 species had experienced severe population declines or extinction, and there is little evidence suggesting these trends have improved in recent years [5]. Primary reasons for declines are summarized by Collins and Storfer [7] and include the spread of invasive species, increasing infectious disease outbreaks, patterns of global climate change, and human land use practices. Of these, human land use is arguably one of the most readily identifiable negative impacts on amphibian populations.

Wetland habitats are often drained and altered to accommodate development of agriculture and urban expansion, with devastating effects on local amphibian populations [8–10]. According to Mitsch and Gosselink [11], the decline in the number of wetlands across the world varies by region from 33% to more than 90%. Habitat loss and fragmentation may exacerbate the negative impacts associated with other causes of declines such as habitat degradation, resulting in decreased mating success and increased susceptibility to other biotic and abiotic factors (e.g., [7, 9, 12–14]).

1.2. Creation and Restoration of Wetland Habitat. In recognition of the importance of wetland ecosystems to both biotic (e.g., species richness, food chain and biodiversity support, habitat provision) and abiotic (e.g., elemental cycling, hydrologic buffering, climate stabilization) processes, numerous policies and regulations have been enacted to mitigate the loss of wetland habitat. The United States has actively pursued the restoration of wetland habitat through a de facto national policy of "no net loss," although no national wetland protection law exists and these ecosystems are regulated by a suite of land use and water quality regulations. Wetland protection policies have evolved in the past two decades from simple area replacement strategies to incorporation of methods that attempt to evaluate lost and subsequently restored or created function. Principal among these attempts to move beyond simple area replacement is the Hydrogeomorphic approach to assessing wetlands functions (HGM; [15–17]). The HGM approach regionalizes wetland functional assessment and incorporates reference wetland condition assessments based on geomorphic position and hydrologic characteristics.

Estimating the ecological success of created and restored wetlands is complex, multifaceted, and site- and project-specific. Compared to analyses of area replacement, useful analyses of ecological functional replacement require considerable time, financial resources, and ecological expertise [18–20]. Little information exists concerning whether the ecosystem functions of created and restored sites sufficiently compensate for those lost in the original wetlands [21]. Moreover, the ecological goals of wetland creation and restoration projects are often unclear or inappropriate for a given restoration project design, producing conflicting results and unsuccessful restoration attempts [22, 23].

Efforts to identify appropriate reference wetlands for comparative evaluation may not follow established scientific protocols or be simply overlooked or never undertaken [22, 24]. In the United States, some attempts have been made to combine the HGM approach with abundance estimates of aquatic bioindicator species using various indices of biotic integrity (IBIs; [25–27]). Given the controversy surrounding assessment approaches, and thus determination of reference conditions, Stein et al. [28] argue that wetland management needs should drive the selected approach, and not the other way around. Finally, monitoring of created and restored wetlands is frequently inadequate, and when conducted primarily focuses on wetland hydrology, biogeochemistry, and vegetation, with little emphasis on faunal use and abundance [29]. Even when faunal colonization is an explicit restoration objective, assessment procedures often fail to recognize the importance of nontarget species richness and related ecological function [30, 31]. Given the importance of faunal activity to healthy wetland function [11], this dearth of information suggests a need for evaluative studies of faunal use of created and restored wetlands.

2. Important Considerations for Amphibians

2.1. Aquatic Habitat. For most amphibians with complex life cycles [32], standing or slow-moving water is necessary for the egg and tadpole development stages [33]. Thus, aquatic habitat quality can be an important determinant of amphibian species composition, richness, and abundance [34, 35]. Wetland-breeding amphibian species vary substantially in developmental timing strategies and aquatic habitat preferences [33]. However, several aquatic habitat features generally appear to benefit amphibians, including lack of predatory fish [36, 37], lack of eutrophication [38, 39], and presence of aquatic macrophytes [40, 41]. Macrophytes increase habitat complexity, and thus can reduce predation pressure by creating refuge zones for larval amphibians [42, 43]. Although nutrients are important for phytoplankton growth [44], which is a primary food source used during the tadpole stage for most wetland-breeding species [33, 45], many amphibians are sensitive to high levels of ammonium and nitrate, low pH, and low levels of dissolved oxygen [46–48]. Further, eutrophication can potentially increase pathogenic infections [49].

Wetland hydroperiod is also important [33]. Long periods of standing water could potentially result in high species richness because species with both short and long developmental periods could utilize the wetland. However, many species have evolved to breed in ephemeral water bodies, and some typically will not utilize wetlands with long hydroperiods [50], which are vulnerable to fish colonization and increased interspecific competition and predation [51–53]. For example, a positive correlation between amphibian species richness and depressional wetland hydroperiod was observed in the southeastern United States, but many species adapted to ephemeral wetlands were not found in wetlands with long hydroperiods [54].

2.2. Upland Habitat. Wetland-breeding amphibians require suitable aquatic and terrestrial habitat for long-term persistence [13]. Based on 21 species investigations, anuran (frog and toad) home range sizes were between $1\,m^2$ and $1{,}900\,m^2$, with a median of $40\,m^2$ [33]. Based on 13 species investigations, salamander home range sizes were between $0.1\,m^2$ and $90\,m^2$, with a median of $4\,m^2$ [33]. Rittenhouse and Semlitsch [55] found that 50% and 95% of amphibian species investigated ($n = 11$) remained within 93 m and 664 m, respectively, of wetlands during nonbreeding seasons. Many amphibians are specialized for particular upland habitat types, and populations will not persist in suboptimal habitat (e.g., 17 amphibians are endemic to longleaf pine (*Pinus palustris*) savanna ecosystems in the southeastern United States; [56]). Thus, upland habitat can be critically important to long-term persistence of amphibian populations.

2.3. Wetland Connectivity and Configuration. Population sizes naturally fluctuate for many wetland-breeding amphibian species, primarily in relation to annual weather variability [2, 57]. Colonization from surrounding water bodies is often important for long-term persistence of populations and subpopulations [58, 59]. Further, because probability of colonization is inversely related to distance traveled [13], the establishment of several wetlands in close proximity to one another is typically optimal for long-term persistence [60]. However, amphibians are vulnerable to road mortality, and thus wetland complexes that are bisected by roads can be problematic [14, 61, 62].

While in general increasing wetland density and connectivity benefits amphibians, there are situations where this can run counter to conservation goals. Florance et al. [63] concluded that artificial water points (e.g., cattle troughs) served as dry season refuges for invasive cane toads (*Bufo* [*Rhinella*] *marinus*) in Australia, which aided in range expansion of this species. Gaston et al. [64] showed that probability of reproduction in the endangered Houston toad (*Bufo* [*Anaxyrus*] *houstonensis*) increased exponentially with number of calling males, and indicated that increasing wetland density in suboptimal habitat could negatively impact this species by decreasing toad density at individual wetlands.

Thus, careful consideration of the placement of wetlands within the surrounding landscape is warranted.

3. Amphibian Use of Created and Restored Wetlands

For the purpose of this review, we included only peer-reviewed studies. We recognized created and restored wetlands as distinct from enhanced and treatment wetlands built specifically for water quality improvement, per Mitsch and Jørgensen [23], and focused only on those studies that addressed the conversion of an existing upland or shallow-water area to wetland habitat (created), or an attempt to return a wetland to a previously occurring wetland condition (restored). We omitted studies that addressed improvement of existing wetland function (enhancement) or creation of new wetlands for water quality improvement and contaminant removal (constructed/treatment). This distinction permitted us to focus on studies addressing the mitigation of wetland habitat loss due to development or environmental change.

It bears noting that treatment wetlands have been shown to support diverse populations of amphibians and may be viable replacement habitat (e.g., [65, 66]). However, treatment wetlands for polluted waters do not typically consider faunal use in their designs, and may actively restrict wildlife from the site using exclusion barriers, trapping, and other habitat modifications that promote water quality improvement while reducing the presence of wildlife [67]. Moreover, this topic has received little attention in the literature. As such, the use of treatment wetlands as amphibian habitat necessarily fell outside the scope of this review.

We found 37 peer-reviewed articles that explicitly addressed amphibian use of created or restored wetlands (Table 1). Twenty-six of the studies included controls in their investigation, which were either reference wetlands or historic survey data. The majority of studies were conducted in the United States ($n = 26$) and surrounding land cover types were primarily forest or agriculture. Species richness or abundance of some or all species was greater at created or restored wetlands versus reference wetlands in 54% of studies, similar in 35% of studies, and lower in 11% of studies.

3.1. Aquatic Habitat. Thirty-three studies addressed the influence of aquatic habitat differences on wetland creation or restoration success. Two aquatic habitat variables were discussed in nearly all of the papers, presence or absence of fish and wetland hydroperiod. With the exception of anurans in the families Ranidae and Bufonidae, amphibian occupancy and abundance was typically negatively associated with presence of fish [41, 60, 68–74], especially for newts [75–77]. In particular, sunfish (*Lepomis* spp. [41, 60, 69, 71, 73, 75]), goldfish (*Carassius auratus* [41, 76, 77]), and largemouth bass (*Micropterus salmoides* [41, 60, 73]) appeared to negatively influence amphibians. The apparent positive association between *Rana* spp. and fish presence could be primarily consequent of both taxa utilizing permanent wetlands [29, 78, 79]. However, studies have shown that fish can increase tadpole survivorship of *Rana* and *Bufo* through predatory invertebrate reduction [80, 81], as well as through reduction of predatory amphibian larvae [82]. In addition, amphibian larval palatability influences predation levels, and both *Bufo* spp. and *Rana* spp. have been found to be unpalatable to some fish species [83, 84]. Finally, gape-limitations of smaller-bodied fish can reduce predation on amphibian larvae [85].

Created and restored wetlands were typically larger, deeper, and had longer hydroperiods than natural wetlands, and in general larger wetlands with longer hydroperiods resulted in greater species richness [86–90]. Based on seven survey years at 10 constructed and 10 reference wetlands, Petranka et al. [86] found that occupancy did not differ between created and reference wetlands for the four salamander species investigated. Further, although occupancy at created wetlands was lower for the eastern newt (*Notophthalmus viridescens*), it was significantly higher for the six anurans investigated. Brand and Snodgrass [88] investigated use of created and natural wetlands in suburban and forested landscapes by six anurans over two survey years. Calling activity occurred almost exclusively in created wetlands, and larvae were found only in created wetlands. Brand and Snodgrass [88] speculated that the short hydroperiods in natural wetlands in their system would prevent reproductive success, possibly due to changes in natural hydrology caused by surrounding landscape alterations.

Although most of the studies found the longer hydroperiods associated with created wetlands to be positively associated with amphibian use, the observed relation was sometimes dependent on the wetlands being free of fish. For example, Julian et al. [72] found that spotted salamander (*Ambystoma maculatum*) and wood frog (*Rana* [*Lithobates*] *sylvatica*) egg masses were less likely to be found in created than natural wetlands, and suggested the primary driver of this result was presence of fish in created wetlands. In most cases wetlands with an intermediate hydroperiod (i.e., wetlands that hold water for several months each year but are not permanent) had the highest species richness because they allowed most amphibian taxa to complete larval development while minimizing fish colonization [88, 91].

In most studies, amphibian species richness and abundance was positively associated with presence and abundance of emergent vegetation [41, 68, 74, 77, 89, 92, 93]. Presence of emergent vegetation was positively associated with reproductive success of the Columbia spotted frog (*Rana luteiventris*) and eastern long-toed salamander (*Ambystoma macrodactylum*) at created ponds in Idaho [41]. Crested newts (*Triturus cristatus*) were more likely to colonize wetlands containing submerged aquatic vegetation [77]. Lesbarrères et al. [89] determined that number of vegetation strata positively influenced species richness and diversity at created ponds in France. Green frog (*Rana* [*Lithobates*] *clamitans*) occupancy of restored wetlands in Canada was positively influenced by percent cattail (*Typha* spp. [93]). However, Porej and Hetherington [71] found that amount of emergent vegetation did not influence amphibian species richness at created wetlands in Ohio, USA. Similarly, Lehtinen and Galatowitsch [94] determined that aquatic vegetation cover

Table 1: Summary information for 37 peer-reviewed articles investigating amphibian use of created and restored wetlands.

Author	Location	Wetland type	Upland habitat[1]	Reference comparison
Babbitt and Tanner [69]	Florida, USA	Created	Grazing	None
Baker and Halliday [68]	Britain	Created	Agriculture	Controls
Balcombe et al. [29]	West Virginia, USA	Created and restored	Various	Controls
Beebee [76]	Britain	Restored	Grazing	Historic survey
Bowers et al. [95]	South Carolina, USA	Restored	Forest	Controls
Brand and Snodgrass [88]	Maryland, USA	Created	Forest and suburban	Controls
Chovanec et al. [70]	Austria	Restored	Various	Controls
Colding et al. [96]	Sweden	Created	Golf course	Controls
Cunningham et al. [78]	Maine, USA	Created[2]	Forest	Controls
Dietsch et al. [138]	South Carolina, USA	Restored	Old field	None
Fuller et al. [79]	California, USA	Created	Various	Controls
Galán [92]	Spain	Created	Forest	Controls
Henning and Schirato [91]	Washington, USA	Created and restored	Grassland	Controls
Joly and Grolet [75]	France	Created	Forest and grassland	None
Julian et al. [72]	Delaware, USA	Created	Forest	Controls
Juni and Berry [139]	South Dakota, USA	Created and restored	Grassland	Controls
Lee et al. [97]	Taiwan	Restored	Forest	Controls
Lehtinen and Galatowitsch [94]	Minnesota, USA	Restored	Agriculture and urban	Controls
Lesbarrères et al. [89]	France	Created	Agriculture	Historic survey
Mazerolle et al. [103]	Canada	Restored	Peatland	Controls
Mierzwa [100]	Illinois, USA	Restored	Agriculture	Controls
Monello and Wright [41]	Idaho, USA	Created	Agriculture	None
Nedland et al. [104]	Wisconsin, USA	Restored	Agriculture	Historic survey
Palis [105]	Illinois, USA	Created	Agriculture	None
Pearl and Bowerman [140]	Oregon, USA	Created	Forest	None
Pechmann et al. [90]	South Carolina, USA	Created	Forest	Controls
Petranka and Holbrook [60]	North Carolina, USA	Created	Forest	None
Petranka et al. [86]	North Carolina, USA	Created	Forest	Controls
Petranka et al. [98]	North Carolina, USA	Created	Forest	Controls
Petranka et al. [73]	North Carolina, USA	Created	Forest	Controls
Porej and Hetherington [71]	Ohio, USA	Created	Agriculture	None
Rannap et al. [77]	Estonia	Created and restored	Various	Controls
Shulse et al. [74]	Missouri, USA	Created	Various	None
Simon et al. [87]	Maryland, USA	Created	Urban	None
Stevens et al. [93]	Canada	Restored	Various	Controls
Touré and Middendorf [114]	Maryland, USA	Created	Forest	Controls
Vasconcelos and Calhoun [50]	Maine, USA	Created	Forest	None

[1] Primary upland habitat listed when applicable
[2] Created by American beavers (*Castor canadensis*).

did not influence amphibian species richness at restored wetlands in Minnesota, USA.

Several studies addressed the influence of slope on amphibian use of created and restored wetlands [71, 74, 77]. The presence of a shallow littoral zone was positively associated with amphibian species richness at created wetlands in Ohio, USA [71]. Shulse et al. [74] determined that relative abundance of American toads (*Bufo* [*Anaxyrus*] *americanus*) and boreal chorus frogs (*Pseudacris maculata*) at created wetlands in Missouri, USA, was negatively associated with wetland slope. However, Rannap et al. [77] did not find a significant relationship between either wetland slope or width of the shallow littoral zone and relative abundance of crested newts or common spadefoot toads (*Pelobates fuscus*) in restored ponds.

3.2. Upland Habitat. Ten studies assessed the influence of surrounding upland habitat on wetland creation or restoration success, with only two failing to detect an influence of the upland habitats. Bowers et al. [95] found that tree planting in and near riparian zones did not influence amphibian species richness for species during initial restoration stages at the Savannah River Site in South Carolina, USA. Petranka et al. [86] determined that distance from forest cover did not influence colonization rates or species richness at a mitigation site in North Carolina, USA. Although the remaining studies determined that adjacent upland habitat was important, results were dependent upon habitat preferences of the species investigated. Brand and Snodgrass [88] found that wood frogs used forested wetlands more than suburban wetlands, but in general, species richness was greater at suburban wetlands. Crested newts preferred golf course ponds, whereas smooth newts (*Triturus vulgaris*) preferred adjacent parklands [96]. Simon et al. [87] found that forest cover within 500 m of wetlands was a better predictor of amphibian species richness in Maryland, USA, than differences among created wetlands. Shulse et al. [74] found that salamander and spring peeper (*Pseudacris crucifer*) abundances were negatively associated with percent cropland in the surrounding landscape, and Monello and Wright [41] found that distance from agricultural land was positively associated with Columbia spotted frog (*Rana luteiventris*) reproduction.

Three studies showed that roads adjacent to created wetlands negatively influenced presence of amphibians [74, 87, 97]. Conversely, Petranka et al. [86] did not detect an association between species richness or number of egg masses and distance to paved roads for wood frogs and spotted salamanders at created ponds in North Carolina, USA, and Balcombe et al. [29] noted that proximity of created wetlands to major roads did not seem to negatively affect anuran abundance. Pechmann et al. [90] and Lehtinen and Galatowitsch [94] speculated that roads may have acted as dispersal barriers for colonization of created wetlands in South Carolina, USA, and restored wetlands in Minnesota, USA, respectively.

3.3. Wetland Connectivity and Configuration. Sixteen studies addressed the role of connectivity and configuration on wetland creation or restoration success. These studies assessed the influence of availability or density of source wetlands, but did not explicitly investigate the influence of spatial arrangement. Newt colonization was heavily dependent on source wetlands in close proximity [68, 75–77, 82]. In a study that investigated both local scale (e.g., hydroperiod, fish presence) and landscape scale (e.g., elevation, wetland density) variables, wetland connectivity was the most important variable for predicting high species richness [78]. Lehtinen and Galatowitsch [94] determined that distance to source ponds was an important factor in predicting amphibian species richness and speculated that the lack of colonization for four species was due to poor dispersal abilities. Shulse et al. [74] found that surrounding pond density or percent wetland in the surrounding landscape was positively associated with abundances of five amphibian species at created wetlands in Missouri, USA. Wetland complexes with variable hydrologic regimes were found to increase potential for restoration success by catering to species-specific preferences and buffering effects of weather variability and disease outbreaks [60, 73, 77, 82, 98]. Further, Petranka and Holbrook [60] indicated that a "patchy population" wetland complex design, characterized by large variability in wetland size, hydroperiod, and spatial proximity, was better than a metapopulation design. A patchy population design allows for adaptive habitat switching, thus maintaining a high probability of population persistence within the wetland complex.

Habitat corridors can be important for restoring or maintaining wetland connectivity, and several studies considered the influence of corridors in their investigations. Rannap et al. [77] found that created wetlands surrounded by forest cover were colonized by amphibians from source wetlands more quickly than those surrounded by meadows. Vasconcelos and Calhoun [99] documented wood frog and spotted salamander movement patterns to and from restored wetlands in Maine, USA, and found that both species preferred to move through forested habitat compared to meadows. Lee et al. [97] determined that type of corridor influenced connectivity among restored wetlands in Taiwan, with wet areas containing dense vegetation being the most used, and drier meadows near roads being the least used. Chovanec et al. [70] investigated amphibian use of restored riparian areas along a heavily modified stretch of the Danube River in Austria. They found wetlands hydrologically isolated from the river had greater amphibian species richness and a larger number of successfully breeding species, but corridors along the river improved landscape-scale wetland connectivity. Bowers et al. [95] investigated amphibian colonization of a restored bottomland hardwood forest corridor in South Carolina, USA, and found no differences in relative abundance or diversity between restored and nonrestored corridors three years after the restoration efforts. However, the authors predicted that restoration attempts would be successful in the long term, as the restored plant community developed into a mature forest. Finally, several studies indicated that upland habitat composition was important for connectivity among wetlands [71, 75, 76, 100].

4. Species-Specific Responses to Wetland Creation and Restoration

In this section we summarize species-specific responses that have been observed for North American amphibians. To ensure broad applicability, we limited our review to species that were explicitly considered in at least eight papers.

4.1. American Toad. American toads (*Bufo* [*Anaxyrus*] *americanus*) are habitat generalists found throughout much of the eastern United States and Canada [101, 102]. Of the 15 studies we reviewed that investigated the American toad, only one did not find the species utilizing created or restored wetlands, in this case man-made bog pools [103]. However, it also was not found at reference wetlands included in the study, likely due to acidic conditions [103]. Brand and Snodgrass [88] found that American toads exclusively used stormwater and created wetlands, which was likely related to their larger sizes and reported longer hydroperiods than natural adjacent wetlands. However, Brand and Snodgrass [88] speculated that upland habitat alteration had altered the hydrology of the natural wetlands. This species colonized created and restored wetlands rapidly [104, 105], and relative abundances in most studies were similar to reference wetlands [29, 92]. Unlike many other amphibians, presence of predatory fish did not seem to negatively influence use of created and restored wetlands by American toads [71, 73, 74]. American toad tadpoles have been shown to be toxic to some fish and invertebrate predators [106–108], and thus wetlands containing fish may not be highly detrimental to reproductive success. However, Petranka and Holbrook [60] found that American toads avoided restored ponds containing wood frog tadpoles, likely due to their predatory nature [109]. Finally, this species appeared to prefer ponds with shallow slopes [71, 74].

4.2. Bullfrog. Bullfrogs (*Rana* [*Lithobates*] *catesbeiana*) have one of the largest natural ranges of North American amphibians, stretching from northern Mexico across the central and eastern United States to southern Canada [102]. However, the species has also been introduced throughout much of the western United States, and is potentially contributing to declines of several amphibian species [101]. Indeed, three of the studies reviewed here included bullfrogs outside of their natural range [41, 79, 91]. Of the 14 studies we reviewed that investigated the bullfrog, all of them reported bullfrog use of created and restored wetlands. Wetlands with long hydroperiods (i.e., wetlands that do not typically dry every year) are necessary for successful bullfrog reproduction due to a long larval stage [110], and created wetlands typically had longer hydroperiods than natural wetlands [71, 74, 86]. Bullfrog use of created and restored wetlands was positively associated with pond depth [78], and density of wetlands in the surrounding landscape [74]. Presence of fish did not deter wetland use [41, 71, 91].

4.3. Green Frog. The distribution of green frogs (*Rana* [*Lithobates*] *clamitans*) extends throughout the eastern United States and southern Canada [102]. This species selects wetlands with long hydroperiods due to a long larval stage, as well as adult habitat preference for aquatic environments [101]. Of the 16 studies we reviewed that investigated the green frog, only one showed that it did not use created or restored wetlands, possibly due to limited dispersal ability [94]. Indeed, several studies reported delayed wetland colonization for green frogs [50, 90]. Wetland use was positively associated with hydroperiod and density of surrounding wetlands, and presence of fish did not deter use [71, 73, 74]. Green frog relative abundance was typically higher at created and restored wetlands than reference wetlands, potentially due to longer hydroperiods in the created and restored wetlands [29, 86, 88, 93].

4.4. Wood Frog. Wood frogs (*Rana* [*Lithobates*] *sylvatica*) have the largest distribution of any North American amphibian, extending from the east-central United States to northern Canada and west to Alaska [101, 102]. This species is an explosive breeder with a short larval period, which allows it to breed in ephemerally flooded pools [111]. Outside of the breeding season, the wood frog resides in the surrounding terrestrial environment, and strongly prefers forested habitat [112, 113]. Of the 13 studies we reviewed that investigated the wood frog, all of them reported wood frog use of created and restored wetlands. Wood frogs were found to rapidly colonize created and restored wetlands [60, 104]. In most studies this species used created and restored wetlands more than natural wetlands, which were typically larger and had longer hydroperiods [86–88, 93]. However, wood frogs showed a strong aversion to wetlands inhabited by fish [72, 78], and abandoned created wetlands after fish colonization [60].

4.5. Spotted Salamander. Spotted salamanders (*Ambystoma maculatum*) are found across the eastern United States and southeastern Canada [102]. This species occupies terrestrial habitat when not engaged in breeding activity, and prefers forested environments [101, 113]. Of the 10 studies we reviewed that investigated the spotted salamander, only one did not find the species utilizing created or restored wetlands. However, detection at the reference site consisted of only one individual [114]. Use of created, restored, and reference wetlands varied among the studies [71, 72, 86]. However, in all cases presence and relative abundance of the spotted salamander was negatively associated with the presence of fish [60, 71–74].

5. Recommendations for Wetland Creation and Restoration

Currently the literature on amphibian use of created and restored wetlands is limited to a small number of species, primarily in North America. However, based on these studies, wetland creation and restoration may be effective for enhancing amphibian abundance and diversity, and thus may be a valuable tool for mitigating amphibian population declines [115]. There was no indication that "artificial" wetlands were inherently less suitable for amphibian use than natural wetlands. Rather, amphibian occupancy and abundance was strongly related to species-specific habitat associations and requirements, as well as dispersal ability.

These studies indicate that needs and preferences of target species should be a major consideration in wetland creation and restoration [77, 91, 116, 117]. Wetlands that are constructed or restored with the goal of providing high-quality habitat for amphibians must consider both the aquatic and surrounding terrestrial habitat, as well as colonization potential. The uplands surrounding managed wetlands are often referred to as "buffer zones," and are typically ≤30 m in width surrounding the wetland for those areas wherein protective legislation exists [118]. Buffer zones ≤30 m are clearly not sufficient for most anurans, which require 100 m or more [33, 55]. Based on empirical habitat use investigations, Semlitsch [119] suggested that buffer zones for salamander populations should extend at least 164 m from the edge of a wetland. Further, Semlitsch and Bodie [120] determined that core habitat zones for anurans were between 205 m and 368 m from the edge of a wetland. Thus, it is clear that maximizing the value of wetland creation to amphibians will require the integration of policy concerning surrounding upland habitat.

In addition to protecting habitat around wetlands from human development (e.g., buildings and roads), the habitat structure of surrounding uplands is important and should be managed for target species [100, 121, 122]. For most threatened and endangered amphibians, and indeed most wildlife species, habitat loss and degradation are principle drivers of long-term declines [3, 5, 123]. Barring disease outbreaks [124, 125], amphibian species that are of greatest conservation concern are typically habitat specialists unable to adapt to human-influenced terrestrial or aquatic habitat changes [126–128]. Thus, preserving or restoring upland systems can be essential for long-term success of wetland restoration programs, and the influence of upland habitat on wetland connectivity should be explicitly considered in restoration programs [93, 129].

It is apparent from this review that there is still much knowledge to gain concerning creation and restoration of wetlands for the benefit of amphibians. We found that many studies were observational in nature, and lacked rigorous experimental design or statistical frameworks. Although this was not surprising given the studies were conducted in real systems with corresponding experimental limitations, the variability in experimental design and data collection made it impossible for us to analyze these data using meta-analysis techniques. Despite these limitations, we believe the following patterns emerged from these studies, which are useful for assisting with future wetland creation and restoration efforts: (1) colonization was influenced by proximity to source wetlands (a function of dispersal capability) and upland habitat connectivity (a function of habitat selection); (2) wetlands with intermediate hydroperiods supported the greatest number of species; (3) presence of aquatic vegetation and shallow slopes increased amphibian use; (4) presence of fish decreased use for most amphibians; and (5) positive results from breeding habitat creation were apparent in the short-term (typically within one to two years), whereas upland and corridor habitat restoration projects required longer time periods to be effective, particularly in forested habitats.

Of potential concern is the replacement of seasonal wetlands with more permanent wetlands, which was apparent in nearly all of these studies, and appears to be a common outcome of wetland creation projects [130, 131]. The influence of biotic interactions on community structure tends to increase as water permanence increases [132–134]. Lengthening of wetland hydroperiod increases predation potential (e.g., through fish colonization), and in some cases promotes invasion by nonnative amphibians. For example, Fuller et al. [79] found that extended wetland hydroperiods due to the creation of side channels and mine tailing ponds along the Trinity River in California, USA, increased habitat suitability for the invasive bullfrog. Similarly, Maret et al. [135] concluded that replacement of seasonal marshes with permanent cattle tanks in Arizona negatively impacted endangered Sonoran tiger salamanders (*Ambystoma tigrinum stebbinsi*) by increasing invasions of fish and bullfrogs. Because hydroperiod dynamics exert such a strong influence on amphibian communities, we recommend that managers consider the surrounding wetland community when engaging in wetlands creation initiatives [136]. Bedford [137] provided a conceptual background for this approach.

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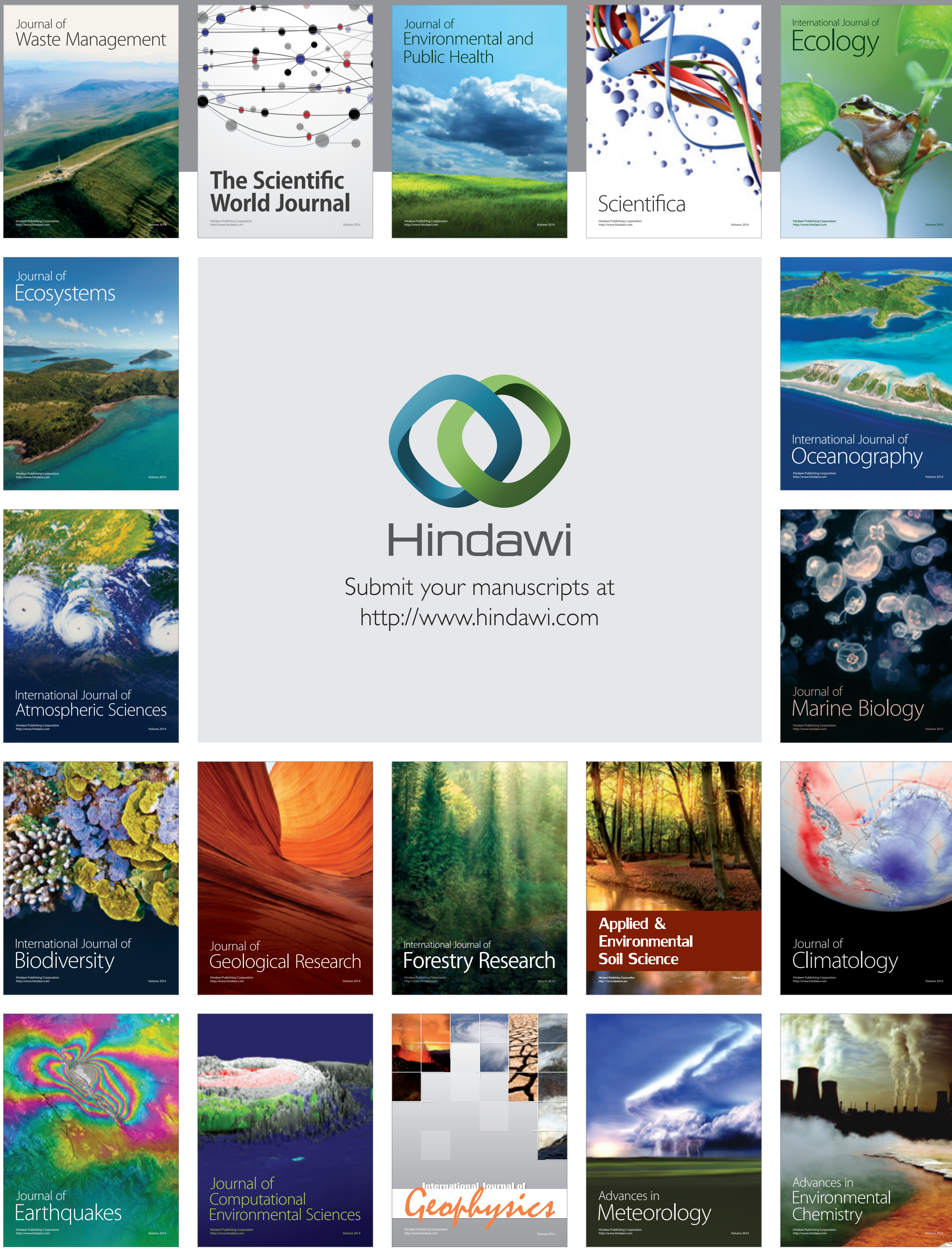
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