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Turfgrass and Environmental Research Online

...Using Science to Benefit Golf

University of Missouri researchers report how golf courses can be used to bolster amphibian populations. They provide management recommendations that include golf course design features, adaptive procedures, monitoring progress and success, developing conservation partnerships, and outreach that superintendents can employ to successfully fill this environmental stewardship role.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

Editor

Jeff Nus, Ph.D.
1032 Rogers Place
Lawrence, KS 66049
jnus@usga.org
(785) 832-2300
(785) 832-9265 (fax)

Research Director

Michael P. Kenna, Ph.D.
P.O. Box 2227
Stillwater, OK 74076
mkenna@usga.org
(405) 743-3900
(405) 743-3910 (fax)

Golf Courses Could Bolster Amphibian Communities

Raymond D. Semlitsch, Michelle D. Boone, and J. Russell Bodie

SUMMARY

Golf courses have the potential to serve as sanctuaries for amphibians, and other wildlife species. However, design and management must focus on the biological needs of amphibians, including aquatic breeding habitats, terrestrial core habitats surrounding wetlands, complementation of aquatic and terrestrial habitats, and connectivity among wetlands.

- For aquatic habitats, we recommend that fish be eliminated and that a diversity of pond types be created or maintained to mimic natural wetlands in the region.
- Aquatic habitats must also be buffered from chemical runoff by using BMP and IMPs, and be monitored for effectiveness.
- For terrestrial habitats, we recommend that all wetlands be surrounded by a core habitat of forest and native grasses or a combination extending 150 -300 meters from the water and uninterrupted by barriers such as roads.
- Terrestrial connectivity of wetlands is essential for overland movement of amphibians, recolonization, and for long-term persistence of populations.
- Education and outreach with local, regional, and national groups on amphibians and golf is essential to staying informed, modifying management strategies, and maximizing the benefit to humans and wildlife.
- If recommendations detailed in this paper are taken seriously, we strongly believe that golf courses can become a place where amphibians can thrive, regional diversity can be bolstered, and amphibians can become a sentinel for a healthy ecosystem.

Many species of wildlife are declining and we are facing a general biodiversity crisis world wide. One of the primary reasons for this crisis is the loss and alteration of natural habitat for species (53). As human populations expand, wildlife are displaced and their needed resources eliminated. Nowhere is this more apparent than in many fast-developing regions of the United States where commercial and residential development have taken a toll on natural habitats. Further, along with development for living space for humans, we crave green recreational areas to pursue leisure pastimes such as golf and enjoying the outdoors. In fact, in the United States, more than 24.5 million men, women, and youth spend 2.4 billion hours playing on one of 16,000-plus golf courses (50). Golf courses impact the U.S. economy by generating an estimated $18 billion each year (50).

One of the central tenets of conservation biology is that the protection of biodiversity must be balanced with land use. Managing landscapes with an eye for both human use and preservation of natural resources can create a win-win situation for humans and wildlife (40). Considering that the average golf course consist of more than 150 acres of green space (70% is rough, non-play areas) and there are over 16,000 golf courses in the United States, we believe there is great potential for golf courses to serve as sanctuaries for many wildlife species.

We present the perspective that golf courses can play a significant role in the protection of biodiversity by applying biological principles for

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RAYMOND D. SEMLITSCH, Ph.D., Curators' Professor; Division of Biological Sciences, University of Missouri, Columbia, MO; MICHELLE D. BOONE, Ph.D., Assistant Professor; Department of Zoology, Miami University, Oxford, OH; J. RUSSELL BODIE, M.S., Scientist/Project Manager, Audubon International, 507 Crooked Oak Drive, Pawleys Island, SC.

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The greatest amphibian diversity is actually associated with ponds that dry for a short portion of the year. Pond drying increases amphibian diversity at sites because it eliminates fish and reduces insect predators as well as large competitors.

the management of amphibian communities to golf course habitats. We break down the habitat needs of amphibians into several components that include: 1) aquatic breeding habitats, 2) terrestrial habitats surrounding breeding sites, 3) complementation of aquatic and terrestrial habitats, and 4) landscape factors such as percent forest cover and habitat connectivity within the golf course and with surrounding properties. Last, we provide management recommendations that include design features, adaptive procedures, monitoring progress and success, developing conservation partnerships, and outreach. Our goal is to provide managers with biologically determined criteria and techniques for bolstering the diversity of amphibians on golf courses.

Aquatic Habitat Needs

The first consideration for supporting pond-breeding amphibians is the aquatic environment. Although the aquatic environment is often only used by amphibians for a small portion of the life cycle (weeks to months for most species), the environmental conditions in the pond will influence which species survive, and how many tadpoles or larvae will transform into juvenile frogs or salamanders that migrate into the terrestrial environment to join the adult population. Studies in natural ponds find between 3 - 5% of the amphibian eggs laid in the pond survive through metamorphosis, which allows for sustainable populations (3, 44, 48). Removing factors that reduce survival unnaturally can help promote healthy, diverse, and persistent amphibian communities.

Amphibians are known to use man-made ponds, like water hazards, sediment retention basins, or farm ponds, so golf course ponds can be managed in such a way to promote amphibian abundance and diversity. There are three key factors to consider when establishing amphibian communities. First, eliminating fish from ponds is a critical step, because ponds without fish allow for greater abundance of amphibians and more diverse communities. The presence of fish eliminates most amphibian species through predation on eggs, larvae, and juveniles, and through competition for food resources (8, 21, 24, 45). Additionally, fish can also carry diseases that are associated with amphibian mortality (54), especially stock fish obtained from hatcheries.

Man-made ponds are frequently stocked with fish to control mosquitoes or algae; however, amphibians can serve the same role in the aquatic environment (2, 25), as well as insect control in the terrestrial environment, but without stocking costs and efforts, and without negatively affecting native populations. Researchers have found that removing fish by either draining ponds or repetitive netting can allow amphibian communities to recover (51).

One way to eliminate fish invasions into ponds or from accidental or purposeful release is to maintain temporary ponds that support diverse amphibian communities. While common sense might suggest that permanent ponds would be better for amphibians, the greatest amphibian diversity is actually associated with ponds that dry for a short portion of the year. Pond drying increases amphibian diversity at sites because it eliminates fish and reduces insect predators as well as large competitors. Many insects live part or all of their life cycle in ponds-many of these are voracious predators that can eat amphibians 10 to 20 times their own size.

While some level of predation is natural and even beneficial to amphibian communities, large numbers of insect predators or large bodied over-wintering insect larvae can significantly reduce amphibian populations. Larvae of many amphibians of early spring breeders often have fewer predator defenses because they have evolved in ponds where insect predation was naturally low. Additionally, permanent ponds favor amphibian species with long larval periods that typically exceed one year, like bullfrogs and green frogs. The larger tadpoles of bullfrogs and green frogs have a greater ability to secure resources and can negatively affect smaller tadpoles of native species that have to reach metamorphosis in a shorter amount of time (7). The negative effect of bullfrogs has been associated with amphibian declines especially in areas where they have been introduced (17, 20).

The timing of pond drying to reduce predators and competitors is also important and should mimic the natural cycle, or hydroperiod, of filling and drying. Premature drying ponds in the spring or early summer will reduce the number of amphibian species with longer larval periods, like salamanders and newts, so for this reason should be avoided. Drying ponds for short periods or biannually in the late summer or fall will be adequate to exclude fish predators, reduce the number of insect predators, and reduce populations of bullfrogs that can negatively impact amphibian communities. Further, pond drying also promotes the natural oxidation of sediments and release of essential nutrients, which will help support healthy amphibian communities.

The negative effect of bullfrogs has been associated with amphibian declines especially in areas where they have been introduced.

While characteristics associated with pond hydroperiod and the predators or competitors that inhabit the pond are important, chemical contamination is another factor that can influence aquatic communities. Because golf courses are routinely treated with chemicals and fertilizer, wetlands on golf courses are potentially exposed to contaminants. Additionally, contaminants can be carried aerially, or through precipitation or in ground water, which can further augment the chemical mixture that aquatic communities are exposed to. Contamination and chemical mixtures can be directly lethal to amphibians and to critical components of their food web (like algae, zooplankton, and insects). For instance, studies at expected environmental concentrations with some commercial formulations of glyphosate have shown that the contaminant can result in direct larval mortality.

Indirect effects are just as or more important, however. Indirect effects are those that do not affect individual physiology or behavior, but instead affect the species of interest through changes in the food web, such as decreases in food resources or decreases in the number of predators. Tiny zooplankton and algae are generally more sensitive to insecticides and herbicides, respectfully, than are amphibians. Because zooplankton are the food resources for larval salamanders, reduction in zooplankton can result in larval death by starvation, even though environmental concentrations may not be directly lethal to the larvae. For instance, mole salamander larvae exposed to sublethal, but realistic, concentrations of the insecticide carbaryl have reduced survival and reduced size at metamorphosis resulting from a negative impact on their food resource-zooplankton; exposure over time would put the salamander (as well as zooplankton) populations at risk of extinction (6, 30).

Likewise, herbicides can reduce food resources for frog and toad tadpoles which are predominantly herbivorous, while insecticides and fertilizers can increase algae. Therefore, herbicides can negatively impact amphibians while insecticides that are not directly lethal can increase food resources while potentially reducing the abundance of insect predators (6). Reduction in food resources can increase mortality and lead to reproductive failure and increase the potential for extinction at the pond. However, removing predators completely can increase larval survival to levels where competition for food resources is so great that a large portion of the population die due to starvation or leave the pond at a smaller size.

In addition to altering the food web, contaminants can also have other effects on amphibians. There is increasing evidence that sublethal chemical exposure can make amphibians more susceptible to disease and parasites, which in the long-run will compromise population stability (9). Additionally, many contaminants have endocrine-disrupting properties, which means they can affect sexual development and reproduction. For instance, the contaminant atrazine (a common herbicide) has been associated with hermaphroditism and feminization in males at levels well below the US EPA drinking water standard (18, 19).

Many contaminants appear to have endocrine-disrupting properties, and such effects may also compromise the sustainability of populations if a significant portion of the population is sterile or all one sex. For these reasons, it would be ideal to minimize the potential for ponds to be exposed to contaminants by increasing no spray zones or vegetative buffers, which will help filter contaminants so that increased concentrations of contaminants will not reach the aquatic environment. Also, using chemicals only when necessary rather than proactively should improve water quality for pond breeding amphibians and other species that live in golf course aquatic habitats.

Tadpole Survival in Golf Course Ponds

We recently conducted a study on several golf courses where we placed a total of 40 enclosures in two golf ponds and two reference ponds. Into each enclosure, we placed tadpoles of American toads and southern leopard frogs and larvae of spotted salamanders; half of these enclosures also included five over-wintered bullfrog tadpoles. We found greater tadpole survival in golf course ponds compared to reference sites.

This outcome may be surprising, but can be easily explained by a reduction of insect predators found in golf course ponds, as well as greater food resources-both of which could be attributed to chemical contamination. This suggests that amphibians could survive in golf course ponds or other habitats that receive some chemical contamination. Yet interestingly, over-wintered bullfrog tadpoles negatively affected survival to metamorphosis of amphibians whether on golf course or reference ponds. This result highlights the importance of creating environments that are less favorable to competitors and predators of amphibians in order to support diverse amphibian communities.

Managing healthy populations requires that each component of the food web remains functional. The way both the aquatic and terrestrial environments are managed is key to the type of amphibian community that can be supported. Amphibian communities are distinguished to some extent by the types of pond communities they use: forest or grassland. The surrounding landscape will influence the amount of light a pond receives, how productive the pond is in terms of food resources (such as algae, the food base of the community), the temperature of the water, and the length of time the pond holds water.

Some amphibian species such as the spotted salamander shown above are associated with forests.

These factors will influence what type of species you can anticipate to successfully use a pond. For instance, some amphibian species are associated with forests (including spotted salamanders, wood frogs, gray treefrogs) while some are associated with grasslands (including northern leopard frogs, chorus frogs), and still others are found in both (including American toads, southern leopard frogs, newts). Knowing which species inhabit a particular type of pond allows you to make informed management decisions that will support all or most species naturally found in similar communities in your region (consult a state or regional amphibian guide book or local expert). It also indicates that a diversity of pond types are essential for bolstering a full complement of amphibian species.

Careful thought of the community you hope to support can be beneficial, because all amphibian communities are not equal. While amphibians frequently appear at newly created wetlands, there are conditions that will favor more or less diverse communities. The least diverse communities are very likely ones that contain bullfrogs only, which often results with the presence of fish in permanent ponds. Having bullfrogs in ponds is not a sign of successfully managing a site for amphibian population diversity, in fact, it indicates just the opposite. This species has been widely introduced around the world where it has become a pest species, caused amphibian extinctions, and reduced abundance of native amphibian populations. Further, bullfrog tadpoles seem more tolerant to chemical contaminants than other species, which may further increase bullfrogs' competitive advantage in a pond.

Designing and constructing aquatic environments that support diverse amphibian communities can be accomplished through periodic drying of wetlands in the late summer to eliminate or reduce fish and bullfrog populations, and through reduced chemical contamination. These straightforward techniques can increase the likelihood of supporting amphibians in a critical portion of their life cycle, and could help buffer amphibian populations from declines in regions experiencing rapid habitat loss and alteration.

Terrestrial Habitat Needs

Although many amphibians can be seen in ponds around golf courses, for most species, the majority of their time is actually spent on land. In fact, species like the spotted salamander or wood frog in the eastern U.S. may only enter ponds for one night a year to lay eggs and then spend the remaining 364 days in the forest surrounding ponds. Aquatic habitats are important for breeding adults, and for the growth and development of larvae but after metamorphosis, juvenile amphibians leave the pond to find food and refuges from the summer heat and over-wintering sites in terrestrial habitats.

We have only recently begun to discover where and how far amphibians go after breeding and what habitats are important for their survival and for persistence of the population. Ponds are often used for breeding by a single population. They are faithful to that pond, and migrate to and from the pond each breeding season. They also appear to be faithful to the terrestrial habitat surrounding ponds. We know that individuals migrate in and out of the pond in the same place each year and that they travel several hundred meters away from ponds into the forest (142 - 289 m; 462 - 939 feet; estimates for 32 species from Semlitsch and Bodie, 47), or fields depending on species preference. This distance varies among species with salamanders traveling less than frogs and toads, and toads traveling farther, especially western U.S. species traveling as much as 1,000

Eliminating fish from ponds is a critical step because ponds without fish allow for greater abundance of amphibians and more diverse communities.

Spadefoot toads are often associated with temporary wetlands located in grasslands.

meters. We also have evidence to show that females of some species like gray treefrogs and boreal toads travel farther than males (38).

What this means is that the breeding pond and its surrounding natural vegetation, such as forest, form a habitat unit or "core habitat" that is essential for completion of the amphibian life cycle and that any efforts to bolster amphibians must consider it as a single management unit. The alteration, destruction, or truncation of this habitat could compromise the ability of some amphibians to persist. These threats would lower the chances of juveniles and adults to grow, survive, and reproduce by decreasing the quality or quantity of resources or by forcing individuals to migrate through habitats that increase risks of mortality (e.g., roads with heavy vehicle traffic, mowed fairways, parking lots).

Although no direct manipulation has been conducted to demonstrate the consequence of habitat loss of varying amounts of forest, a population dynamic model has shown that any truncation of terrestrial habitat around breeding ponds leads to higher probabilities of local population extinction (16). Also, Homan et al. (22) has shown with a land-use analysis that spotted salamanders are absent from vernal pool breeding sites in the northeast U.S. when percent forest cover in the surrounding landscape falls below 30%. Further, population models have also indicated that protection of the terrestrial portion of the juvenile and adult population is even more critical to persistence of species than protection of the aquatic larval population (15). Biological information indicates that more attention should be focused on the quantity and quality of terrestrial habitats for amphibians than previously given.

Amphibians do not use terrestrial habitats randomly but appear to select a number of important macro- and micro-habitat features in the terrestrial environment. For example, the green frog makes repeated forays away from and back to the breeding pond during the summer. Being a prolonged breeding species, green frogs obtain food to fuel breeding activity all summer and food appears more abundant away from the breeding pond than near. Such forays average 36 m from the pond edge (28). Later in the year green frogs migrate from aquatic breeding sites to small creeks and spring seeps where they over-winter in flowing water, deep in cracks and root masses (27).

In Missouri, we have found that when gray treefrogs leave the pond after breeding, they forage almost exclusively in large trees some distance from the pond and that they prefer white oaks (23). They prey primarily on ants that are abundant on the tree trunks and they use knotholes as daytime refuges from desiccation. Another study in Missouri using radio-tracking showed that after wood frogs leave breeding ponds in spring they emigrate an average of 110 meters away and down into rocky ravines where the microclimate is presumably cooler and moister than on ridges during hot dry summers (38). Several studies have shown that in regions with karst topography, pickerel frogs rely on caves for over-wintering (36, 37). Last, a recent study has confirmed what others had previously only suggested that mole salamanders use small rodent burrows as underground refuges and that spotted salamander abundance is correlated with the density of vertical and horizontal small mammal burrows (31).

These findings indicate that it is not just distance from the pond or extent of the area that is critical for protection of terrestrial amphibian populations, but attention must be focused on protection of specific macro- and micro-habitat features necessary for life history functions from alteration. It becomes imperative that we delineate areas of protection that provide the area but also include specific critical habitats as determined for the particular set of species in your region.

Complementation and Connectivity of Habitats

Current information indicates that amphibian conservation also needs to consider the spatial context of aquatic habitat, terrestrial habitat, and populations. That is, we need to maintain the complementation between aquatic and terrestrial habitats (e.g., foraging and over-wintering habitats) so that each is readily available for their respective life history function. This means that aquatic habitats are readily available to adults for breeding and for growth and development of larvae. Further, the terrestrial core habitat needed by metamorphosing juveniles and adults after breeding should be directly adjacent to the pond. Separation of aquatic and terrestrial habitats by fairways, roads, or buildings would likely disrupt or potentially stop natural migrations for many species and lead to population declines.

Also, if we consider a pond and its surrounding terrestrial habitat as a population "patch", then we need to know what is the density of patches in the landscape and what is the degree of habitat connectivity among patches. Defining the distribution of multiple populations, also known as the metapopulation concept, is important for conservation because single populations are inherently unstable for long-term persistence (43).

Why is connectivity among populations important for amphibians? In one of the pioneering metapopulation studies by Gill (14), he found that red-spotted newt populations varied tremendously in their ability to produce offspring. Most populations produced few, if any, offspring and were considered declining or "sink" populations. A couple populations produced a lot of young, and were considered "sources" for colonists to sink populations. Further, he found that the source populations producing lots of offspring changed over time.

The important point for conservation is that if most populations cannot replace dying adults with new offspring at a rate equal to those dying, especially if they suffer from drought, fish predation, disease, or chemical pollution, the population could go extinct. Such populations can only be "rescued" if they are supplied with colonists migrating from source populations. The critical issue for management of terrestrial habitat is whether immigrants from source populations can readily move overland to colonize sink populations. Two factors become important for determining the probability of an individual successfully immigrating (12): 1) geographic distance between the adjacent populations, and 2) habitat resistance to overland movement.

It is evident from several independent studies that individual amphibians have an upper limit of approximately 1,000 - 1,200 meters to how far they can travel overland (4, 26). Assuming this is true for all amphibians, it suggests that populations (pond-patches) that make up a metapopulation need to be within this distance. If we look at the distance between wetlands in a natural landscape like the South Carolina coastal plain, we find an average inter-wetland distance of 471 m (47). If wetlands are filled or drained and the density goes down, the average inter-wetland distance goes up. Thus, ponds or

The important point for conservation is that if most populations cannot replace dying adults with new offspring at a rate equal to those dying, the population could go extinct.

streams on or near golf courses should not be separated by more than an average distance of 200 - 500 meters, and ideally never more than 1,000 meters.

Further, the habitat between ponds must be suitable for overland travel of amphibians, that is, there must not be any resistance or barriers. Species vary tremendously in their ability to travel through terrestrial habitats. Forest-dependent species like spotted salamanders are often reluctant to cross 100 meters of grassland or pasture (39), whereas species like the American toad and green frogs readily travel across mowed grass and through typical suburban landscapes. Maintaining corridors of natural vegetation between ponds (on or off course property) will facilitate amphibian movement and insure that populations do not go extinct permanently.

Management Recommendations

The success of a management program to bolster amphibians depends on three important elements: 1) the potential or existing course layout, design, and construction; 2) the routine monitoring and management of all land uses within the course property; and 3) the capacity to seek new information and to inform others. Many superintendents will find it natural to apply this program to amphibians because it is also the approach for creating a healthy, playable golf course.

However, rather than focusing solely on turfgrass, the superintendent should consider a broader context. Questions to ask include: What amphibian species may occur in my local area? What aquatic and terrestrial habitats are they associated with? Do these habitats occur or have the potential to occur on my golf property? What threats do these species face and how can I reduce or remove these threats on my property? What can be done to bolster amphibian populations? The answers to these questions will help define the amphibian resources on your property and place management within a larger context focused on habitats and landscapes. Table 1 lists the major recommendations that are detailed below.

Course Layout, Design, and Construction

Opportunities exist to provide amphibian habitat whether starting with new or renovated construction or improving an existing golf course. Natural and created water bodies, including seasonal shallow "wet areas", are the best starting points as these are sites of amphibian breeding. As detailed above, wetlands and streams are functionally integrated with the uplands that surround them. As detailed above, amphibians use 142 - 289 meters (462 - 939 feet) of land outward from their breeding sites as core terrestrial habitat. Every effort should be made to preserve or restore substantial acreage of existing natural upland vegetation around wetlands as core amphibian habitat by routing golf features around them. If necessary due to property constraints, a portion of the golf envelope may encroach within the upland, but most (75% or more) of the upland should be managed as native habitat (34) and the area immediately adjacent the wetland (within 93 m; 302 feet) should be left undisturbed (38).

Furthermore, corridors suitable to amphibian movement among core habitats to maintain connectivity should be preserved or restored with a recommended minimum width of 50 meters (163 feet). Golf courses, with many discrete linear- and angular-shaped features arranged throughout a landscape, provide an ideal development model for providing both core habitats and corridors to connect them in the spaces between and among golf holes (see Figure 1). For long-term persistence of amphibians on the course, it is important to connect core habitats not only within your property but also to potential core habitats adjacent to your property - migrating amphibians do not recognize property lines!

Water bodies created on golf courses are another opportunity to augment existing wetlands and streams and provide more "source" populations or "stepping stones" for amphibian migration. The model for golf course pond design for amphibians is best derived from natural wetlands in your region, in general, a mix of small (<0.2 hectares [0.5 acres]) and large ponds (> 2.0 hectares [5 acres]), with open and closed canopy,

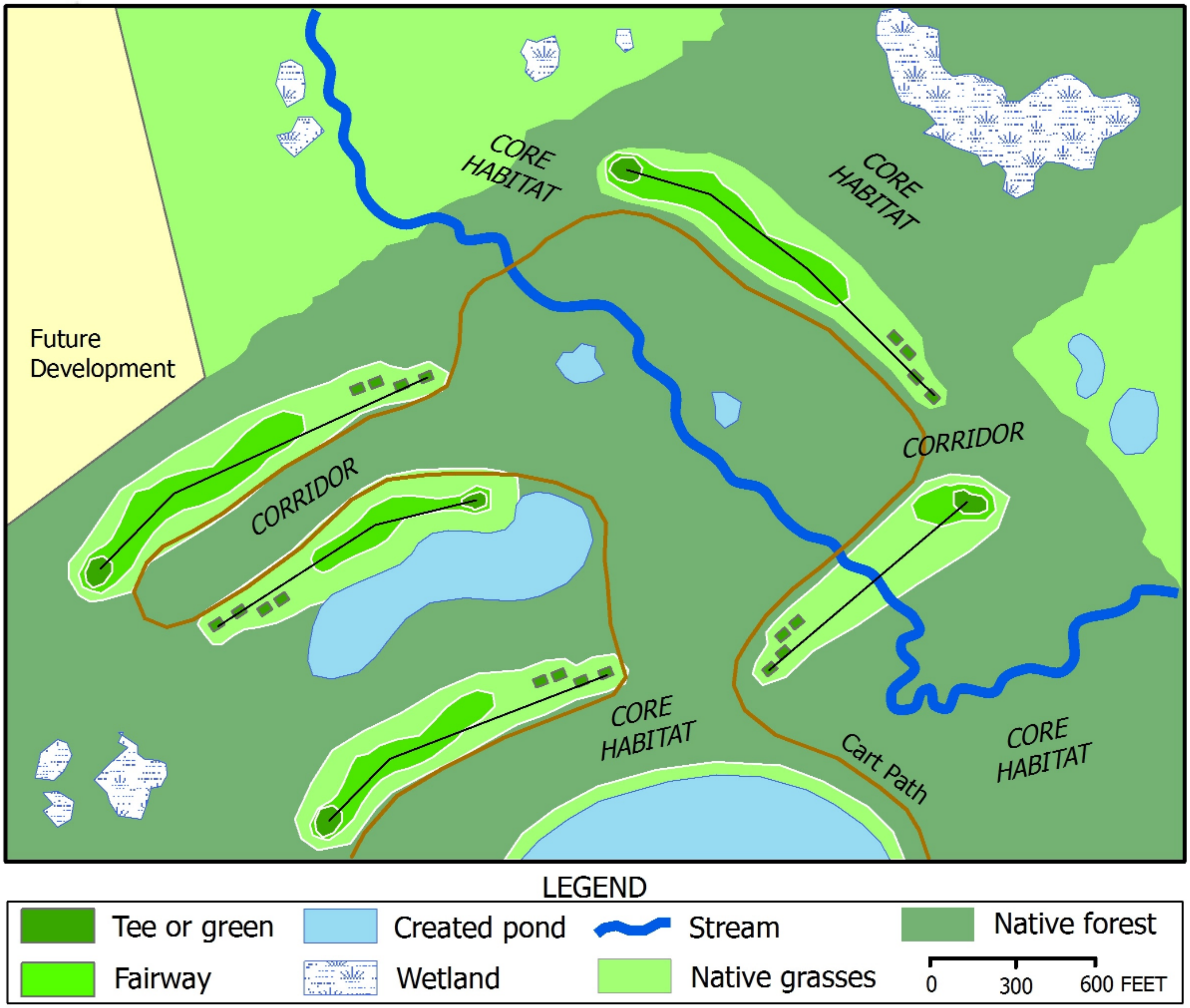

Figure 1. Good amphibian habitat (as shown above) requires complementation between aquatic and terrestrial habitats so that each is readily available for their respective life history function. Separation of aquatic and terrestrial habitats by fairways, roads, or buildings would likely disrupt or potentially stop natural migrations for many species and lead to population declines.

and with depths ranging 15-60 cm (6-24 inches).

A diversity of wetland types creates variation in seasonal filling and drying and will support a greater diversity of native amphibians in both wet and dry years. Natural densities of wetlands range from 0.48/km^2 in South Carolina to 0.59/km^2 in Maine (13, 47). Further, open canopy pond margins should have a littoral shelf planted with native emergent vegetation with low slopes of 15:1 or less (34). The final design should include natural and created aquatic habitats within 200 - 500 meters apart.

Innovative and effective storm water designs (49) often include measures such as littoral shelves for their inherent treatment and storage capacity and may therefore serve many purposes other than storm water management. Existing golf courses with no opportunity to reconstruct pond margins or add created wetlands may be able to launch floating rafts of emergent plants or created islands (5). A key aspect of ponds for many native amphibians is the absence of predatory fish and bullfrogs. Shallow ponds that dry seasonally or created ponds that can be drained manually are likely to simulate some elements of natural wetlands if water levels are managed in synchronicity with native wetlands in the region. As with existing wetlands and streams, created ponds are not complete without surrounding native upland vegetation consisting of both closed and open canopy.

New or renovating golf courses must be especially attentive to damage of existing amphibian populations using wetlands or streams and associated terrestrial core habitats during clearing and construction. Besides the potential for direct damage to individuals, alteration of nutrient cycling, water quality, natural hydrology, and vegetative structure may occur. Solutions include creating and following a comprehensive resource management plan prior to site work, flagging wetlands and core terrestrial habitat boundaries, minimizing site disturbance, incorporating vigilant construction management, and protecting core areas.

Because storm water is the primary vector for contaminants, protection of water resources also provides protection for amphibian species. Measures such as effective "best management practices" (BMPs) including preventative and structural controls preclude contamination of core habitats and corridors. The most effective way to protect both groundwater and surface water is by using a comprehensive BMP systems approach (49).

Management and Monitoring

Best management practices on the golf course are not relegated only to construction but are best integrated into course design and implemented during construction and long-term management. Combining BMP and "integrated pest management" (IPM) programs together with efficiency in rate and timing of fertilizer application and irrigation will substantially reduce or eliminate water quality problems (32, 33) which directly impact aquatic amphibian breeding sites. Tenets of IPM programs include the use of resistant turf varieties, cultural and biological control of pests, and good nutrient management techniques (29). In addition, effective management of the maintenance area is an important part of water quality management. The general approach is to isolate all potential contaminants from soil and water, not to discharge any material onto the ground or into surface water bodies, and to minimize irrigation,

Restricted practices should include "no mow, no spray" 25-feet-wide buffers adjacent to all core habitats including uplands, followed by another 25-feet-wide buffer where organic fertilizers only are allowed.

Recommendations for bolstering amphibians on golf courses

1) Preserve and restore existing seasonal or temporary wetlands and streams, including their natural ability to fill and dry typically in late summer / autumn.

2) Provide created ponds without fish by regularly netting or by draining during late summer / autumn.

3) Preserve, restore, and create many sizes and types of ponds, wetlands, and streams with and without forest canopy and no more than 200-500 meters apart.

4) Include forested and grassed uplands around aquatic sites that extend 150-300 meters from the water with management for native habitat at least in the 100 meters closest to the water. Manage aquatic and surrounding terrestrial areas as amphibian "core" habitat.

5) Augment core habitats with minimum 50-meter-wide corridors of managed native forest and grasses.

6) Use Best Management Practices (BMPs), Integrated Pest Management (IPM), and a management plan during construction and maintenance of the golf course especially to reduce or eliminate pollutants.

7) Monitor surface and ground water quality to assess the effectiveness of the management plan.

8) Monitor amphibian populations for successful reproduction, juvenile recruitment, and a diverse group of species.

9) Adapt management as needed based on monitoring and current research.

10) Reach out to local, regional, and national groups to educate and be educated on amphibians and golf.

Table 1. Summary of major recommendations for bolstering amphibians on golf courses

fertilizer, and pesticide use through the use of BMPs and IPM (29).

These broad-scope turfgrass management practices have the cumulative effect of reducing or eliminating direct and indirect impacts on amphibians, but another layer of protection is establishing restrictive management zones throughout the course. Management zones are areas that have distinct management practices that correspond with their position in the watershed and proximity to amphibian core habitats. Restricted practices should include "no mow, no spray" 25-feet-wide buffers adjacent to all core habitats including uplands, followed by another 25-feet-wide buffer where organic fertilizers only are allowed. All surface drainage from the course should be filtered through "management zone" vegetation or infiltrated prior to reaching core amphibian habitats (29).

Minimal management of terrestrial core

habitats and corridors is necessary or even desirable for amphibians. Although it may be essential to occasionally cut and remove dead trees or snags for safety reasons, allowing fallen leaves, limbs, and trees to accumulate has been shown to be a positive microhabitat feature for wildlife including amphibians, especially salamanders (10). Likewise, control burning may be a common management practice in some regions to reduce fuel and fire risks in forests or prairies, and for controlling invasives. However, little is known about potential effects on amphibians other than burning during the coldest period of the year is likely to do the least harm. Mechanical or chemical measures to reduce or eliminate invasive exotic plants in terrestrial preserves is commonly necessary, but BMP and IPM programs should be followed to reduce direct and indirect amphibian impacts.

Monitoring provides a means to measure the success of the management program. At a minimum, it should encompass sampling groundwater, surface water, and sediment as well as amphibian populations in wetlands and ponds prior to and during construction and during routine maintenance to determine if any detrimental effects on these habitat variables are detected. The goals of the monitoring program are to: 1) provide baseline data, 2) provide data that assess bio-physical conditions, and 3) ensure that the management programs are functioning properly.

Results of the monitoring program provide feedback to the golf course superintendent as a useful management tool. For example, the results of the program are used in determining the correct application rates and timing of pesticides and fertilizers and the effectiveness of course personnel training programs. Finding diverse amphibian communities where successful reproduction, larval development, and recruitment into the adult populations are all occurring is another way to monitor for successful management. Presence of sustainable populations of local frogs and salamanders in all parts of their life cycle can be a biologically meaningful way to monitor terrestrial habitat and water quality. Because frogs and toads have unique calls associated with each species, calling surveys can be used to determine species presence and relative abundance. Many states have local frog call survey teams, which may be willing to help golf courses monitor their amphibian populations.

Education and Outreach

Increasing attention has been focused recently on the interrelationships between golf courses and the environment, in particular on protecting habitat and water resources from contamination by nutrients and pesticides (1, 52). Education and notification of residents and golfers of environmentally sensitive areas is also an important part of the overall management strategy for surface waters and wetlands. Appropriate signs can identify areas that are ecologically sensitive, or that golfers should avoid as well as contain interesting information about species that are of particular focus or concern. The scorecard should also identify these areas, and the starter can also notify golfers of the sensitive areas.

Information should be posted in the golf clubhouse and other high visibility locations. There is great potential for outreach programs linked to local colleges, universities, or conservation groups (e.g., Audubon International) once interested citizen groups, students, professors, or conservation agents are contacted. Information on amphibians (e.g., species lists, reproductive biology, threats, etc.) can now be gathered easily through a number of websites that are maintained by professional biologists and herpetologists such as:

Partners in Amphibian and Reptile Conservation
http://www.parcplace.org

Declining Amphibian Population Task Force
http://www.open.ac.uk/daptf/index.htm

AmphibiaWeb
http://amphibiaweb.org/ index.html

We believe that amphibians can provide a number of hidden benefits to golf courses and the golfing community. First, because pond-breeding amphibians occupy both aquatic and terrestrial environments, amphibians play an integral role in most wetland, stream, and adjacent forest ecosystems (41, 42). As such, they provide a number of functions and services that can be beneficial to all members, including humans. As herbivores, frog and toad tadpoles consume vast amounts of algae, periphyton, and plant material in the aquatic environment that would otherwise clog waterways and create unsightly algal mats caused by fertilizer runoff. As carnivores, salamander larvae consume zooplankton and aquatic insects like mosquito larvae that infest ponds, and in some regions, carry diseases like West Nile virus.

Further, because they emigrate from ponds as metamorphosing juveniles, many of which don't survive, pond breeding species help export nutrients from the aquatic environment into the terrestrial environment, often in large quantities (11). These nutrients are made available to terrestrial plants and often provide food for terrestrial predators such as insects, reptiles, birds, and small mammals. Likewise, because all adult amphibians are carnivores, frogs, toads and salamanders consume large amounts of insect biomass, including pest species like ants, termites, roaches, and mosquitoes. Some researchers have found that amphibians help nutrient cycling to a degree that results in measurable differences in primary productivity where amphibians are present (2). Thus, amphibians provide a number of functions that are part of "healthy" ecosystems that are inherently more stable and presumably need less active management.

There is no doubt that many conservation biologists perceive golf and golf courses as contributing to the growing problem of habitat loss and alteration. However, the recreational needs of the human population are a legitimate and an important use of resources. Yet, balancing the use of these natural resources with the conservation of biodiversity is also important, and as biologists, our ultimate objective.

We have outlined a number of management elements that can be incorporated into existing golf courses and developed into new designs. If these recommendations are taken seriously, we strongly believe that golf courses can become a place where amphibians can thrive, regional diversity can be bolstered, and amphibians can become a sentinel for a healthy ecosystem. It is our hope that amphibians can someday become an integral part of all golf courses and that golfers or anyone hiking along the trails can take pleasure in seeing a school of tadpole feeding in the shallows or listening to the summer trill of chorusing treefrogs.

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