WL 9851-159

Can Golf Courses Be Designed To Enhance Amphibian Diversity on Golf Gourses: Effects of Turf on Amphibian Movements

2000 Final Report

1 November 2000

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ABSTRACT

Research Objectives

(1) Compare immigration and emigration rates of two age cohorts (adult and metamorphs) of pond-breeding amphibians across a forested landscape fragmented by turf.

(2) Assess the effect of grass height on amphibian movements.

(3) Assess amphibian use of experimentally created travel corridors.

(4) Quantify amphibian community structure at golf courses throughout southern New England.

(5) Monitor changes in amphibian population size at a breeding pond following construction of a golf course.

Recent research on movements of pond-breeding amphibians across fragmented landscapes in New England is equivocal and mainly focused on post-breeding dispersal by metamorphs (recently transformed young-of-the-year). I monitored immigration and emigration rates of pond-breeding adult and metamorph amphibians across a forested landscape fragmented by commercial turf fields. I captured 7,122 amphibians in 42,566 trapnights from May 1998 to June 2000. Daily capture rates and daily species richness estimates were >2.2 times greater in forest-interior compared to forest–turf edge; both habitats were approximately 125 m from the same breeding ponds. Adults of 2 species, green frog (*Rana clamitans*) and pickerel frog (*R. palustris*), readily immigrated across a 68-m wide turf field to reach breeding ponds, while turf filtered movements by adults of 6 other species (wood frog [*Rana sylvatica*], spring peeper [*Pseudacris crucifer*], gray treefrog [*Hyla*

versicolor], American toad [*Bufo americanus*], spotted salamander [*Ambystoma maculatum*], red-spotted newt [*Notophthalmus viridescens*]). Movements by metamorphs were less affected by forest fragmentation than adults. Capture rates of metamorphs of 4 species (green frog, pickerel frog, spotted salamander, red-spotted newt) were equivalent in forest-interior and forest–turf edge, whereas metamorphs of 4 species were 5 (American toad) to 165 (spring peeper) times more abundant in forest-interior compared to forest–turf edge. These results indicate that most pond-breeding amphibian species in southern New England are habitat specialists during at least one stage of their complex life cycle, adults tend to be greater habitat specialists than metamorphs, and forest fragmentation is affecting dispersal by amphibian populations in the region.

Experimental evidence found that frogs preferred to move through wooded habitats rather than turf ($P = 0.058$) or barren areas ($P = 0.002$). This suggests that dispersal corridors from ponds to upland wintering areas should be forested habitats. Therefore, we created a series of experimental forested travel corridors during the 2000 field season. Contrary to our initial findings monitoring movements across a fragmented landscape, adults of most species showed no preference for the corridors, while metamorphs of most species were more likely to use travel corridors than cross open habitats.

Surveys of 59 ponds at 32 golf courses in southern New England found that Green Frogs and Bullfrogs dominated most of the ponds (e.g., found in 73% of the ponds surveyed) at golf courses in the region. This is because these species prefer water bodies that are permanently flooded, as their tadpoles take 1-3 years to undergo metamorphosis and disperse from the pond. In contrast, the young of other species of pond-breeding frogs and salamanders only remain in the pond for less than 6 months, and their young are out competed by Green Frog and Bullfrog. A simple management solution may be to modify the hydroperiod length of a pond to increase species richness.

Finally, from 1997 to 2000, we monitored amphibian community structure in a vernal pond, which had a golf course constructed 150 m west of the pond during the summer of 1999. During baseline years (1997-1998), we detected 11 species of amphibians, while post-construction we detected 10 species. In general, population sizes of adults did not fluctuate dramatically following golf course construction, with the exception of Wood Frog, Marbled Salamander, and Red-backed Salamander. The only species that appeared to have declined as a result of golf course construction was Marbled Salamander. However, Marbled Salamander migration coincided with construction of a road 20 m from the pond in Aug-Sept 2000 to a small housing development. Therefore, it was difficult to separate the effects of road construction from golf course construction. In addition, amphibian populations often undergo dramatic population fluctuations in undisturbed ponds.

In summary, our research suggests that amphibians can be sensitive to habitat fragmentation, many species prefer to disperse through forested habitats rather than turf habitats, manipulating grass height does not appear to enhance amphibian movements through an area, and it was difficult to detect any obvious indication of changes in amphibian community structure when a golf course was constructed 150 m from a breeding pond.

INTRODUCTION

Recent research has documented declines and extirpations of a number of amphibian populations (Semlitsch 2000). One principle factor affecting populations is habitat fragmentation (DeMaynadier and Hunter 1995, 1998, 1999; Gibbs 1998). Amphibians can be exceptionally sensitive to changes in microclimate and microhabitat because they have permeable skin that makes them susceptible to desiccation (Feder 1983). Habitat alterations that change local microhabitat conditions can have significant impacts on terrestrial amphibian populations (Petranka 1999). For example, researchers have estimated that plethodontid salamander populations may take 20–70 years to fully recover following clearcutting (Petranka et al. 1993, DeMaynadier and Hunter 1995, Ash 1997).

Amphibians that breed in ponds have complex life cycles that also make them vulnerable to habitat fragmentation. Ponds are used by adults for mating and oviposition and by larvae for development until undergoing metamorphosis (Wilbur 1980). With the exception of a brief breeding season, adults and metamorphs of pond-breeding amphibians typically spend most of their life in adjacent terrestrial habitats (Windmiller 1996, Semlitsch 2000). Therefore, most pond-breeding amphibians have to migrate through a matrix of microhabitats to reach their non-breeding territory (usually <200 m; Semlitsch 1998). DeMaynadier and Hunter (1998, 1999) identified several anurans and caudates in forested regions of Maine that were forest-interior specialists and suggested that salamanders were generally more sensitive to fragmentation and edge effects than frogs. In Maine, two species in particular, spotted salamander and wood frog, avoided edges and recently clearcuts (also see Madison 1997, Windmiller 1996), whereas red-spotted newt was a habitat generalist that readily moved across edges. In contrast, Gibbs (1998) in Connecticut found that capture rates of wood frogs and spotted salamanders were not influenced by proximity to forest edges and suggested that edges did not filter the movements of these two amphibian species. Gibbs did find, as opposed to DeMaynadier and Hunter (1999), that movements by red-spotted newts were significantly affected by habitat fragmentation. Therefore, available evidence from New England is equivocal as to which species may be most impacted by anthropogenic disturbances in the region.

Recent research on the effects of habitat fragmentation on migratory behavior of pond-breeding amphibians has primarily focused on emigration dispersal by metamorphs and post-breeding dispersal by adults (DeMaynadier and Hunter 1998, 1999; Gibbs 1998), with less is known about habitat requirements of adults during migration to breeding ponds (but see Windmiller 1996, Madison 1997, Dodd and Cade 1998). Adults tend to be site faithful to the same breeding pond (Shoop 1965, Stenhouse 1985), whereas metamorphs are the age class that disperses to new breeding ponds (Gill 1978, Berven and Grudzien 1990). In southern New England, recent habitat fragmentation is primarily the result of increases in residential development and associated infrastructure (e.g., power lines, shopping centers, golf courses)(Windmiller 1996). The number of humans living in southern Rhode Island is expected to double in the next 20 years, therefore we need to gain a clearer understanding of habitat requirements of adult and recently metamorphosed pond-breeding amphibians if we hope to protect this unique group of vertebrates in this region.

Objectives of this research were to (1) compare immigration and emigration rates of two age cohorts (adult and metamorphs) of pond-breeding amphibians across three habitat types: (a) forest-interior, (b) an edge located between a commercial turf field and a deciduous forest, and (c) a second edge located between a commercial turf field and forest, but also situated adjacent to a potential dispersal barrier (i.e., a railroad track); (2) assess the effect of grass height on amphibian movements, (3) assess amphibian use of travel corridors, (4) quantify amphibian community structure at golf courses throughout southern New England to determine what species are currently inhabiting golf courses, and (5) quantify the impact of golf-course development on amphibians near the Beaver River Golf Course.

STUDY AREA AND METHODS

Objective 1, assessing amphibian movements across various habitat types:

We conducted fieldwork in forested habitat just north of the Kingston campus of the University of Rhode Island, Washington County, Rhode Island. Two Amtrak electrified, railroad tracks bordered the western boundary of the study area (Fig. 1). A permanent pond, utilized by breeding bullfrog (*Rana catesbeiana*) and green frogs (P. W. C. Paton, unpublished data), was located 150 m west of Railroad array. Commercial turf fields, which were the primary habitat features that fragmented the landscape, were located on the western and central sections of the study area. All turf fields were actively mowed throughout the study period, with grass height usually maintained at <5 cm. Five ponds utilized by breeding amphibians with varying hydroperiods were located in the center of the study area; a sixth pond just east of Field array was not used by breeding amphibians because it had a short hydroperiod of <50 days (P. W. C. Paton, unpublished data). Amphibian abundance and productivity was monitored at 2 ponds (Pond #1 and #2, Fig. 1). Metamorphs produced from arrayed ponds included wood frog, spotted salamander, spring peeper, American toad, and gray treefrog. The two largest ponds in the middle of the study area were not encircled with drift fence; both had breeding populations of green frog, bullfrog, and red-spotted newt (P. W. C. Paton, unpublished data).

Areas to the north and south of breeding ponds were dominated by old field and shrub habitats. Breeding ponds were located in a matrix of closed-canopy, mixed deciduous-hardwood forests (red maple [*Acer rubrum*], autumn olive [*Elaeagnus umbellata*], oaks [*Quercus spp.*]), with woods to the east of the ponds dominated by a closed canopy of mature red maples, oaks, and white pine (*Pinus strobus*). Topography was generally flat to the west of breeding ponds, while terrain gained elevation east of breeding ponds; the Woods array was 10 m higher than Pond #1.

We used drift fences with pitfall traps (hereafter arrays) to monitor amphibian movements across the landscape (Gibbons and Semlitsch 1982). We constructed arrays from 1-m tall black, nylon silt fencing. We fabricated 3 straight-line arrays (Woods, Field, and Railroad) and 2 arrays that completely encircling breeding ponds (Ponds #1 and #2; Fig. 1). Woods and Field arrays were approx. equidistant (125 m) from Pond #1. Woods array monitored movements in forest-interior, Field array monitored movements at an edge habitat at the ecotone between a 68-m wide turf field and a deciduous hardwood forest, while Railroad array monitored movements at another edge. We placed pairs of pitfall traps at 10-m intervals on opposite sides of the fence. We fabricated pitfall traps from two number 10 tin cans taped together, 15 cm in diameter and 33 cm deep. Each trap had a plastic funnel, with a 10-cm wide opening cut out of the base of the funnel, to prevent captured amphibians from climbing out of traps. Pitfall traps had holes punched in the bottom to allow rainwater to drain. We checked traps daily starting at approximately 0700 hr, with trapping sessions taking 30 min to 6 hrs to complete depending on capture rates. We recorded species, age, gender, trap number and location (immigration or emigration side of the array), and julian date for each animal captured. Age was based on snout-vent length (SVL) (size criteria for metamorphs: American toad <25 mm, green frog <45 mm, pickerel frog <35 mm, gray treefrog <25 mm, spring peeper <25 mm, wood frog <25 mm, red-spotted newt <25 mm, spotted salamander <40 mm; Klemens 1993, P. W. C. Paton, unpublished data). We toe-clipped all animals to mark previously captured animals, with all animals within a year receiving the same mark. We did not toe-clip arboreal species (gray treefrog and spring peeper). We processed all animals in the field and released them on the opposite side of the fence. We recorded the number of pitfall traps closed daily due various events (e.g., flooding, predatory ants colonizing traps through drain holes) to quantify the total number of trapnights available for each array.

We monitored Woods array (150 m long, 16 pairs of pitfall traps; Fig. 1) and Field arrays (180 m long, 19 pairs of traps) during the same time periods, while Railroad array (70 m long, 8 pairs of traps) was monitored for fewer days due to low capture rates. Woods and Field arrays were surveyed on 548 days from 28 May–17 December 1998 (204 consecutive days), 20 February–30 Sep 1999 (233 days), and 26 February–15 June 2000 (111), while the Railroad array was checked for 333 days from 24 June–31 October 1998 (128 days) and 10 March–30 September 1999 (205 days). We monitored Pond #1 (0.02 ha, 16 pairs of traps) from 27 March–31 October 1998 and 21 February–30 September 1999, while Pond #2 (0.005 ha, 8 pairs of traps) was monitored from 25 February–31 October 1998 and 21 February–30 September 1999. In southern Rhode Island, adult pond-breeding amphibians typically migrated to breeding ponds from late February through early June, while metamorphs emigrated from breeding ponds from mid-June through September (Klemens 1993, Paton et al. 2000). There was also a reduced pulse of post-breeding dispersal by adults in the fall (Kleeberger and Werner. 1983, Klemens 1993, P. W. C. Paton, unpublished data). Therefore, we monitored adult breeding dispersal during two breeding seasons (1999 and 2000) and metamorph dispersal for two years (1998 and 1999).

Overall capture rates (number captured/100 trapnights) at all arrays were based on the cumulative number of immigrating and emigrating adults and emigrating metamorphs. We included terrestrial efts (Klemens 1993) in calculations of red-spotted newt adult capture rates. The cumulative number of trapnights for adult capture rate calculations ranged from 5,173 trapnights at Railroad array, 16,682 trapnights at Woods array, and 20,711 trapnights at Field array. Capture rates for metamorphs were based on animals captured from 15 June–17 December 1998 and 15 June to 30 September 1999 and only calculated for Woods (4,344 trapnights) and Field arrays (5,586 trapnights).

To compare species richness among arrays, we calculated the number of species detected daily at each array and then compared among arrays using a log-likelihood test (G-test, Zar 1984). I was primarily interested in determining how two age classes (metamorphs and adults) of each species moved across this landscape fragmented by turf. We assumed that animals emigrating from breeding ponds in random directions would be captured at equivalent rates at the Woods and Field arrays, since both arrays were approx equidistant from breeding ponds (Fig. 1). We excluded Railroad array from a comparison of immigration and emigration capture probabilities for individual species, as it was considerably farther from breeding ponds than the other arrays and beyond migration distances for adults of most pond breeding amphibians (Semlitsch 1998). A number of abiotic (e.g., precipitation, temperature; Bellis 1965) and biotic factors (seasonal variation in migration chronology, annual variation in productivity; Semlitsch 2000) can affect the number of animals moving across the landscape. Therefore, we compared daily capture rates between Woods and Field array using a paired-t test. Using a paired test minimized the effects of daily variation in precipitation and annual variation in population size for each species. We calculated separate paired-t tests by species for immigrating adults, emigrating adults, and emigrating metamorphs.

To quantify the proportion of metamorph wood frogs and spotted salamanders that actually emigrated ≥125 m from breeding ponds, we first determined the total number of metamorphs in 1998 and 1999 that emigrated from Ponds #1 and #2. We determined the total number of toe-clipped metamorphs captured at Woods and Field arrays, and then calculated the percent of marked animals from Ponds #1 and #2 that actually reached Woods and Field arrays. Animals captured at Pond #1 and #2 did not received a unique toe-clip, so we could not calculate movement patterns for each pond.

Woods and Field arrays did not completely encircle Ponds #1 and #2, but rather surrounded only 330 m to the east and west of ponds (Fig. 1). Because the forest-turf edge was linear, it was not possible to construct a circular array surrounding breeding ponds and simultaneously monitor edge effects. Assuming we built a square drift fence with the shortest distance to breeding ponds approx 125 m (1000 m long, 250 m/side); existing arrays encircled only about 33% of the area within 125 m of the Ponds #1 and #2. Therefore, to calculate the number of metamorphs potentially dispersing 125 m from pond based on captures at Woods and Field arrays, We multiplied cumulative captures at Woods and Field array by a factor of 3.03 (1000 m/330 m).

All statistical analyses were conducted with SPSS (SPSS 1996). When presenting descriptive statistics, we show mean ± SE. All tests were performed at $\alpha = 0.05$.

Objective 2, assessing the influence of grass height and canopy closure on movements

During the 1998 field season, we constructed two square pens (50' on each side) on a 4-ha section of bent grass, which is used by the Turf Grass Group at URI for a variety of experiments. Grass in this area is typically mowed to <0.25" tall to mimic typical golf greens. The perimeter of our experimental pens was encircled with 0.5-m tall silt fence. The pens were subdivided into 4 quarters (25' per side). Each quarter (randomly selected) was mowed to a grass height that mirrored height typically found on golf greens, fairways, and roughs (0.25", 0.5", 1", and >1.0"-2-5"). All experiments were conducted on rainy nights, when amphibians were likely to move (P. Paton, unpubl. data). During the experiment, an individual amphibian (a Wood frog, American Toad, Green Frog, Bullfrog, or Pickerel Frog) was placed in the center of the array underneath an inverted coffee can. Attached to the coffee can was a 100' rope that went through a pulley attached to a 3' tall tripod directly above the can, and then >50' out of the array. Once an animal was placed in the can, the observer moved away from the array and allowed the animal to settle for 30 seconds. The trial began when the can was lifted off the animal, and the animal was allowed to move for 3 minutes. The observer then determined where the animal moved and how far it had moved. Each animal was marked with a small patch of red reflective tape to aid in finding it with a flashlight. Habitat preferences were analyzed with a log likelihood ratio test statistic.

To determine if amphibians preferred to travel in either a wooded overstory/shrub understory or in open habitats, we used Wood Frogs, Green Frogs, Pickerel Frogs, and American Toads for this experiment. We constructed pens with silt fencing measuring 25' wide by 50' long, with enclosures located at the ecotone of two habitats, with 50% of the enclosure in one habitat type and 50% in another. Habitat comparisons included forest versus mowed grass field, and forest versus a barren, sandy substrate. A pitfall trap was placed in each corner of the pen. A single frog was placed in the center of the array underneath a coffee can with the rope system described above attached. Trials lasted for 5 minutes. All experiments were conducted on rainy/humid nights, and animals had red reflective tape attached. The final habitat and distance moved were recorded at the end of the trial. We used a log likelihood ratio test statistic to determine habitat selection.

Objective 3, determining if amphibians will use travel corridors

During the 2000 field season, we created 5 experimental potential travel corridors perpendicular to the Woods array (Figs. 2 and 3). We used a chainsaw and brushcutter to cut the overstory and understory out from five 20 × 10 m blocks. We were interested to see which species of amphibians were more likely to travel in forested travel corridors or open corridors, or if species did not exhibit any habitat preferences while emigrating from or immigrating to travel ponds. We used a chi-square test to compare use between forested and open corridors for each species.

Objective 4, assessing amphibian community structure at existing golf courses throughout the region.

To quantify amphibian community structure at ponds on golf courses in southern England (Rhode Island, Massachusetts, and Connecticut), we sampled 59 ponds at 28 golf courses and 1 commercial turf field during the 1999 field season (Table 3). Based on conversations with superintendents at each course, we attempted to sample every available pond at each course. A crew of 2-3 biologists would sample each pond by dip-netting for tadpoles and salamander larvae. All samples were collected during daylight hours from 06:00

– 15:00, with most samples collected early in the morning. Each pond was sampled with 30 sweeps of a 0.5 m diameter, small mesh dip-net. Data collected at each pond included estimates of size (length and width in meters), depth, vegetation characteristics at each pond, and distance from pond edge to the nearest woods.

Objective 5, Quantifying changes in amphibian community structure in response to construction of a golf course.

We used a silt fence to completely encircle a vernal pond to monitor movements of amphibians at the southwestern corner of the junction of Beaver River Road and Route 138 from 1997-2000 (Fig. 4). The array was originally established in 1997 as part of another study supported by the URI Agricultural Experimental Station. The array was closed in November 1998, but reopened May 1999 when we heard of plans to build the Beaver River Golf Course. We monitored amphibian movements at this site from 19 Mar to 11 Nov in 1997, 12 Feb to 29 Nov in 1998, 22 May to 30 Sept in 1999, and 26 Feb to 19 Oct in 2000. This proposed golf course was approximately 150 m west of the array and provided the unique opportunity to assess short-term impacts of golf course and road construction on an amphibian community. Because the array was not re-opened until May, we missed quantifying population sizes of adult Wood Frogs and adult Spotted Salamanders, however we were able to measure metamorph productivity for both species in 1999.

RESULTS

Objective 1, habitat preferences of adult and metamorph amphibians during migration

We captured 7,122 amphibians from 11 species in 42,566 trapnights (16.7 animals/100 trapnights). Capture rates were lowest at Railroad array (76 captures; 1.5 animals/100 trapnights), moderate at Field array (2,441 captures; 11.8 animals/100 trapnights), and highest at Woods array (4,605 captures; 27.6 animals/100 trapnights; Table 1). Metamorphs accounted for the majority of captures (62.1%) and dominated captures for most species at all arrays, with the exception of two arboreal anurans (spring peeper and gray treefrog). Two species, bullfrog and four-toed salamander (*Hemidactylium scutatum*), had <15 captures and not included in subsequent analyses. Red-backed salamander (*Plethodon cinereus*) was much more common at Woods array than either Field or Railroad array (Table 1), but was not included in subsequent analyses because it is a terrestrial breeding species and does not migrate to breeding ponds (Klemens 1993).

Woods and Field arrays both had 11 species of amphibians, while 9 species were detected at Railroad array. Mean daily species richness was greatest at Woods array (1.64 ± 0.08), moderate at Field array (0.75 ± 0.05), and lowest at Railroad array (0.12 ± 0.03; $G \geq 81.1$, 5 df, $P < 0.001$).

Adults of most amphibian species had significantly higher capture rates in forest-interior compared to forest–turf edge. During immigration to breeding ponds or emigration from breeding ponds, adults of only 2 anurans, green frog and pickerel frog, had equivalent capture rates at Woods and Field arrays (Table 2). Red-spotted newts were more likely to immigrate towards breeding ponds through forest-interior and not across turf, while adult and eft newts emigrated at equivalent rates through forested habitats towards Woods and Field arrays.

During immigration to breeding ponds, capture rates of adult spring peepers, gray treefrogs, wood frogs, and spotted salamanders were 13, 26, 213, and 479 times greater, respectively, in forest-interior compared to moving across a 68-m wide commercial turf field. When emigrating from breeding ponds, adult gray treefrogs were never detected at forest–turf edge, whereas capture rates of other species ranged from 1.9 times greater (American toad), 17 times greater (spring peeper), 42 times greater (spotted salamander), and 106 times greater (wood frog) in forest-interior compared to forest–turf edge.

For metamorphs, capture rates of 4 species (green frog, pickerel frog, spotted salamander, and red-spotted newt) during emigration was not different between arrays in forest-interior and forest-turf edge habitats, whereas capture rates of American toads were 5.3 times greater, wood frogs were 32 times greater, and spring peepers were 165 times greater were in forest-interior compared to forest-turf edge (Table 3). As with adults, no metamorph gray treefrogs were detected during emigration at forest–turf edge.

The Woods and Field arrays appeared to be relatively effective in capturing dispersing metamorphs from breeding ponds. The percentage of metamorphs that emigrated from Ponds #1 and #2 and captured at Woods and Field arrays ranged from 6–11% for wood frogs and 10–15% for spotted salamanders (Table 4). Assuming that Woods and Field arrays surrounded 33% of the area within 125 m of the ponds, as many as 18–33% of wood frog metamorphs and 30–45% of spotted salamander metamorphs produced from Ponds #1 and #2 may have emigrated 125–175 m from breeding ponds during this study.

Objective 2, monitoring the effects of grass height and plant composition on movements

In experiments conducted during 1998 with four grass heights, we found movements were random with respect to grass height ($G = 3.7$, $P = 0.29$; Table 5). This suggests that grass height, at least in the height range we quantified that is typical of current golf courses practices in North America, does not hinder or enhance amphibian movements. This is true for the species we sampled, but we did not have the opportunity to investigate any salamanders or some frogs (Spring Peepers, Gray Tree Frogs, and Wood Frogs), whose movements could be affected by grass height.

We conducted experiments to determine if amphibians (frogs in this case) preferred forested habitats to either turf or barren areas. In both cases, the evidence shows that wooded habitats were preferred over barren ground ($G = 9.2$, $P = 0.002$, Table 6) or turf ($G = 3.6$, $P = 0.058$, Table 7). This suggests that travel corridors from breeding sites to wintering areas designed to have wooded habitats connecting the two areas would be preferred over areas with that have grassy habitat bisecting breeding and wintering habitat.

In addition, we found little evidence that amphibians would readily cross 174 m (570') of turf (although we did have one young marked Pickerel Frog move from the Field array to the Railroad array). Capture rates at the Railroad array were at least 6.5 to 9.3 times lower than the Field and Woods array, respectively (Table 1). However, amphibian readily crossed ~70 m of turf (i.e., the outside of Field array), which is 2-3 times wider than most fairways in New England. This implies that many typical fairways may not represent a travel barrier to many species of amphibians in southern New England. Unfortunately, there is no potential upland habitat to the west of the Field array that represents wintering habitat, which is why relatively more animals might not be on the outside of the Field array.

Objective 3, amphibians use of travel corridors

Throughout the 2000 field season, we monitored migration of 8 species of amphibians past the Woods arrays through forested or open travel corridors. We separated migratory events into adult emigration (i.e., migrating east from breeding ponds, Fig. 2), adult immigration and metamorph emigration. We captured very few metamorphs immigrating to breeding ponds, so do not present those data.

During adult immigration, 2 of 8 species, Spring Peeper and Wood Frog, exhibited a preference for travelling the forested travel corridors, whereas the other species exhibited no preference (Table 8). The pattern for adult emigration was identical to immigration, with only Spring Peepers and Wood Frogs showing a preference for forested travel corridors. There was a tendency for adult Red-backed Salamanders to be captured in forested habitats, although this species is a terrestrial breeding species and does not migrate to breeding habitat (Klemens 1993).

Metamorphs of only two species, American Toad and Green Frog, did not show a preference for forested travel corridors (Table 8). All other species were much more likely to travel via the forested corridor than via the open corridor.

Objective 4, amphibian community structure at golf courses in southern New England

We surveyed 59 ponds at 32 golf courses during the summer of 1999, of which 78% (46 of 59) had amphibians detected (Table 8). The vast majority of ponds (73%) either had

Bullfrog (56%) or Green Frog (53%) tadpoles. Pickerel frogs were much less common, as they were detected in only 10% of ponds surveyed. American Toads were only in one pond (1.7% of ponds surveyed), which also had fish in it), and Spotted Salamander larvae were detected in only 1 pond..

These results are not unexpected because most ponds on golf courses tend to be permanent water bodies (have water year-round) as many are primarily irrigation reservoirs. Both Bullfrogs and Green Frogs have tadpoles that have to overwinter before undergoing metamorphosis, therefore they tend to be found in permanent bodies of water. In contrast, Wood Frogs, Spring Peeper, Gray Tree Frog, and Spotted Salamander young transform within 6 months of hatching, and consequently only need ponds with fluctuating water levels to survive.

Objective 5, monitoring the effects of golf course construction on pond-breeding amphibians:

We gathered two years of baseline data (1997 and 1998) before they initiated construction of the Beaver River Golf Course during the summer of 1999. Eleven species of amphibians were detected during baseline years, of which five species bred at the pond (Am toad, spring peeper, wood frog, marbled salamander, and spotted salamander). Some adult bullfrogs, green frogs, and pickerel frogs resided during the summer in the pond, but there was no evidence of any successful reproduction. Any metamorphs of these last three species were captured on the exterior of the array and probably produced from a permanent pond 200 m to the west of the arrayed pond. In general, population sizes of adults did not fluctuate dramatically at this one vernal pond, with the exception of Wood Frog, Marbled Salamander, and Red-backed Salamander. The only species that appears that it may be declining as a result of golf course construction is Marbled Salamander. However, Marbled Salamander migration also coincided with construction of the entry road for the small housing development, so that might have had a major impact on the animals as well.

During the fall of 2000, further construction was initiated near the array. A small housing development is planned west of the array for construction during 2001 and an entry road was constructed on the south side of the array. This road came within 15 m of the southern boundary of the array, with dirt from the road bed spilling onto the array (actually covering three traps on the exterior of the array until we uncovered them). This road construction may have affected migration of adult Marbled Salamanders to the array, as construction started during August, which coincided with Marbled Salamander migration.

DISCUSSION

Amphibian migration across fragmented landscapes

We documented non-random dispersal of adult and metamorph pond-breeding amphibians in a forested landscape fragmented by turf fields in southern Rhode Island. We monitored movements of amphibians relatively far from breeding ponds (≥125 m), while Dodd and Cade (1998) detected non-random movements of amphibians in the immediate vicinity of a breeding pond in Florida. The majority of anurans and caudates in this study were habitat specialists at some stage during their complex life history because they were significantly less abundant at edge habitats. Avoidance of edge habitats was particularly true for adults, during both immigration and emigration from breeding ponds.

Although the two primary arrays (Woods and Field) during this study were at least 125 m from breeding ponds, large numbers of metamorphs reached both arrays. Semlitsch's (1998) recent meta-analysis estimated that metamorph *Ambystoma* salamanders emigration averaged 70 m from breeding wetlands during their first year. Results from this study suggest that more metamorphs may disperse farther than 70 m during their first fall. We estimated from 10–45% of spotted salamander metamorphs emigrated to Woods or Field arrays from Ponds #1 and #2. DeMaynadier and Hunter (1999) working on 20-m diameter experimental plots with 0.5 m tall drift fences, were only able to capture 34% of wood frog metamorphs placed in the center of the array. They attributed this relatively low capture efficiency to either snake predators or metamorphs were able circumvent the fence. If a substantial percentage of wood frog and spotted salamander metamorphs were able to circumvent Woods and Field arrays during this study, than even a greater percentage of individuals may have emigrated ≥125 m.

The relative abundance of amphibians during this investigation were typical of other studies conducted in forested habitats in New England. Capture rates in the forest-interior at Woods array (28 animals/100 trapnights) were slightly higher than Gibbs (1998) findings (20.5 animals/100 trapnights) in a deciduous forest in central Connecticut, and about twice as great as mature forests in Maine (14 animals per 100 trapnights; DeMaynadier and Hunter [1998]), three upland forest types in New Hamsphire (12 animals/100 trapnights; DeGraaf and Rudis 1990), and forest-turf edge during this study (12 animals/100 trapnights). Habitats surrounding Railroad array were either unsuitable non-breeding habitat (i.e., turf) or significant dispersal barriers (i.e., the Amtrak railroad tracks), which is why capture rates (<2 animals/100 trapnights) were probably so low at this array. In addition, Railroad array was

>400 m from amphibian breeding ponds in the middle of the study area, which is beyond the dispersal distances for adults of most species, but not metamorphs (Gill 1978, Berven and Grudzien 1990, Semlitsch 1998).

Only 2 species, green frog and pickerel frog, were habitat generalists during migration to breeding ponds. Green frogs are among the most widespread anuran in southern New England, commonly occur in degraded urban landscapes (Klemens 1993), and do not avoid edges in Maine (deMaynadier and Hunter 1999). Therefore, the lack of edge effects in movement behavior by adult green frogs was expected. Gibbs (1998) also found that movements of pickerel frogs were not influenced by edges near residential areas and roads, but they did appear to actively follow streambeds when present (see also deMaynadier and Hunter 1999). There were no active streambeds within the confines of this study area, which suggests that stream courses may not always be essential habitat features for dispersing pickerel frogs. Adult pickerel frog can migrate large distances, as Windmiller (1996) found them 0.34 km from the nearest wetland.

Adults of all other species exhibited strong avoidance of edge habitats. Most adult pond-breeding amphibians reside during the non-breeding season in upland forested habitats (Bellis 1965, Klemens 1993, Madison 1997, Windmiller 1996, Semlitsch 2000). Small numbers of adult amphibians did cross turf west of Field array while immigrating to breeding ponds, so a 68-m wide turf field was not an absolute barrier to amphibian movements. In Maine, DeMaynadier and Hunter (1999) found that adult spotted salamanders and wood frogs were edge sensitive and most abundant >40 m from the nearest edge. We also documented that adults of both species were avoided edges during this study. DeMaynadier and Hunter (1999) found that both species preferred closed-canopy forested habitats. In addition, we also found that adult American toads, spring peepers, gray treefrogs, and red-spotted newts avoided forest-turf edge. American toads are generally believed to be habitat generalists (Klemens 1993, deMaynadier and Hunter 1999), so their preference for the forest-interior was surprising. Less is known about movement behavior of arboreal anurans (peepers and treefrogs) away from breeding ponds. In southern New England, spring peepers are relatively widespread and found in a wide variety of habitats, whereas gray treefrogs are less prevalent in urbanizing areas suggesting treefrogs are sensitive to fragmentation issues (Klemens 1993).

DeMaynadier and Hunter (1998) classified metamorph mole salamanders (*Ambystoma* spp.), red-backed salamanders, and wood frog as habitat specialists that preferred forest-interior. In Maine, they documented lower capture rates of these 3 species up to 25 m from clearcut edges within forested habitats. During both years of this study, we found similar capture rates of metamorph spotted salamanders at forest-interior and forest-turf edge, suggesting that metamorphs may consider crossing potential barriers such as turf. However, we was unable to place an array in the center of the commercial turf operation to conclusively determine how far each species might penetrate turf. Gibbs (1998) also found no statistical evidence that metamorph spotted salamanders avoided edges, although he did document lower capture rates near edges. My investigations of movement behavior of metamorph red-spotted newts concur with deMaynadier and Hunter (1998) and contradict Gibbs (1998) findings in Connecticut, as we found that they were habitat generalists. We found no evidence that metamorph red-spotted newts avoid edge habitats, with large numbers captured in forest-interior and forest-turf edge when emigrating. This suggests random dispersal of metamorph newts across the landscape. However, efts and adults did avoid edges during this study.

Metamorph American toads, spring peepers, gray treefrogs, and wood frogs all exhibited non-random dispersal across this fragmented landscape by avoiding forest-turf edge. In particular, capture rates of wood frog and spring peeper metamorphs were 32 and 165 times, respectively, greater in forest-interior compared to edge habitats. These results concur with deMaynadier and Hunter (1998, 1999) for wood frogs, and differ from Gibbs (1998) research in Connecticut. However, Gibbs did document lower capture rates of metamorph wood frogs near forest-residential and forest-road edges, even if he did not find statistically significant evidence that movements were independent of edges.

Available evidence indicates that pond-breeding amphibians can be extremely sensitive to edge effects, even more than many avian populations (Paton 1994). Habitats containing large open expanses, such as golf fairways or large residential lawns, may be dispersal barriers to many species during migratory events (deMaynadier and Hunter 1998, 1999; Gibbs 1998; this study). Pond-breeding amphibians have complex life history strategies (Wilbur 1980) and this study suggests that habitat preferences for a species may change over time. Metamorph amphibians were less likely to avoid edges than adults. We agree with DeMaynadier and Hunter's (1999) recommendation that populations of forest-interior specialists would be enhanced by maintaining connectivity between upland habitats and breeding ponds by retaining travel corridors. Travel corridors should include closed-canopy forests with a dense understory, that would allow dispersal by both metamorphs and adults.

Objective 2, monitoring the effects of grass height and plant composition on movements and Objective 3, amphibians use of travel corridors.

We conducted a number of experiments to assess habitat selection among amphibians. We found that grass height (0.25 to 1 inch tall) had little affect on amphibian movements, as frogs did not select or avoid any grass height. We did find that frogs were much more likely to seek forest/shrub cover, rather than travel in open grass areas when given the opportunity. This is probably why capture rates were over 2 times greater in the Woods array compare to the Field array.

Experimental manipulations of the habitat around Woods array in 2000 were not entirely in agreement with experiments conducted in 1998. We found differences in the response of different age cohorts to the forested travel corridors. Adults migrating to and from breeding ponds did not exhibit strong habitat preferences, only two species were more likely to be captured in wooded travel corridors. In contrast, metamorphs emigrating from breeding ponds were much more likely to travel in forested travel corridors within a forested matrix. This suggests that travel corridors may be used by amphibians, particularly metamorph. More importantly, this suggests that travel corridors are a viable management option for golf course designers and planners.

Results of these experiments and observations of migration across this fragmented landscape suggest that golf course superintendents interested in maximizing amphibian species diversity on golf courses should (a) maximize forest/shrub cover at the edge of fairways, (b) minimize fairway widths, (c) provide shrub/forest cover to potential amphibian breeding ponds.

Objective 4, amphibian community structure at golf courses in southern New England

Our surveys at golf courses throughout southern New England found amphibians will use ponds on golf courses. However, species richness at golf course ponds is relatively low compared what could potentially breed at these sites (Klemens 1993). Species that are typically found in seasonally-flooded ponds (e.g., Wood Frogs, Spotted and Marbled Salamander, Spring Peeper, Gray Treefrog) tend to be absent from ponds on golf courses This is because ponds on golf courses often are permanently flooded because they often provide irrigation water for the course. Ponds that always have water provide ideal habitat for species whose larvae have to overwinter 1-3 years before undergoing metamorphosis (e.g., Bullfrog and Green Frog). This is why 73% of the ponds we surveyed on golf courses throughout the region either had Bullfrog or Green Frog tadpoles. Bullfrog tadpoles can be voracious predators and can out compete the young of other pond-breeding amphibians (e.g., Wood Frog; Klemens 1993). One potential management strategy for superintendents to increase amphibian species richness at golf course ponds is to modify the hydrology of ponds. If ponds were to be drained completely every year, in the early fall (mid-September-early November), that would eliminate Bullfrog/Green Frog production from the pond and allow other species (Spring Peeper, Wood Frog, Spotted Salamander, Gray Treefrog) the opportunity to successfully breed in the pond. This latter management strategy assumes that other pond-breeding species exist near the pond to be managed, and will readily disperse to the pond.

Objective 5, monitoring the effects of golf course construction on pond-breeding amphibians:

Research conducted over the past 3 years found some species will be less affected by the habitat fragmentation that occurs at golf courses (e.g., fairways interspersed among forest patches), while others species tend to be relatively sensitive to habitat fragmentation. We found that adult Green Frogs and Pickerel Frogs will travel across a 68 m (220') wide turf field, suggesting that most fairways do not present a travel barrier for these species. Yet, adults of other species (e.g., Spotted Salamander and Wood Frog) were not captured attempting to cross the turf field, suggesting that a 68-m wide corridor of grass can be a barrier for some pond-breeding amphibians. On the other hand, a 175-m (560') wide turf field apparently impeded virtually all amphibian movements, as we found few organisms crossing such a large expanse of turf. In fact, captures rates were at least 20 times lower in the Railroad array compared to the Field or Woods array. The proximity of the national railroad corridor also presented a substantial travel barrier to amphibians attempting to head east from Hundred Acre Pond, which is another reason why few species or individuals were captured at the Railroad array.

Our results have consistently shown that emigration and immigration movements of both adults and young amphibians to breeding ponds appears to be non-random, at least for certain species. This result suggests the possibility that amphibians have the potential to adapt to habitat manipulations such as golf course construction. It is important to point out that the North Woods study site only 25 years ago was a landfill for the town of South Kingston. In fact, the area is currently an EPA Superfund Site. Therefore, the ponds in the area, such at Trench and Gene's Truck Pond, are artificial wetlands that obviously have been colonized by a broad array of amphibians. This shows that restoration efforts, such as golf course designs, have a great deal of potential to become effective in enhancing wildlife populations such as amphibians.

Data gathered by the Beaver River Country Club, where construction was initiated in May 1999, provides useful empirical information on the effects of golf course construction on amphibian populations. If there were impacts, they would be on wintering individuals, therefore we might expected significant declines in population abundance. However, amphibian populations can vary dramatically among years (Pechmann et al. 1994, Semlitsch et al. 1996), therefore it was difficult to tease apart direct affects of the golf course construction versus road construction.

ACKNOWLEDGEMENTS

I want to thank many undergraduates and graduate students that helped with fieldwork over the course of the study including Gene Albanese, Kate Banick, William Crouch, Salinda Daley, Erik Endrulat, Amelia Jarvis, Michael Huguenin, Eileen LaRosa, Chris Monti, Jay Osenkowski, Kelly Radcliffe, Scott Rush, and Brad Timm. This research would not have taken place without their dedicated assistance. We also thank all the golf course superintendents who graciously allowed on their golf courses, assisted the crew with finding ponds to survey, and lent the crew golf carts for the day to conduct their research; their assistance was vital. Finally, we thank the superintendent, Ray Grandchamp, and owners of the Beaver River Club for assistance with conducting research on their property.

LITERATURE CITED

Ash, A. N. 1997. Disappearance and return of plethodontid salamanders to clearcut plots in the southern Blue Ridge Mountains. Conservation Biology 11:983-989.

Bellis, E. D. 1965. Home range and movements of the wood frog in a northern bog. Ecology 46:90-98.

Berven, K. A. and T. A. Grudzien. 1990. Dispersal in the wood frog (*Rana sylvatica*): implications for genetic population structure. Evolution 44:2047-2056.

DeGraaf, R. M. and D. D. Rudis. 1990. Herpetofaunal species composition and relative abundance among three New England forest types. Forest Ecology and Management 32:155-165.

DeMaynadier, P. G., and M. L. Hunter. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Review. 3:230-261.

—, and —. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology 12:340-352.

—, and —. 1999. Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine. Journal of Wildlife Management 63:441-450.

Dodd, C. K., and B. S. Cade. 1998. Movement patterns and the conservation of amphibians breeding in small, temporary wetlands. Conservation Biology 12:331-339.

Feder, M. E. 1983. Integrating the ecology and physiology of plethonontid salamanders. Herpetologica 39:291-310.

Gibbs, J. P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in southern New England. Journal of Wildlife Management 62:584-589.

Gibbons, J. W. and R. D. Semlitsch. 1982. Terrestrial drift fences with pitfall traps: An effective technique for quantitative sampling of animal populations. Brimleyana 7:1–16.

Gill, D. E. 1978. The metapopulation ecology of the red-spotted newt, *Notophthalmus viridescens* (Rafinesque). Ecological Monographs 48:145-166.

Kleeberger, S. R. and J. K. Werner. 1983. Post-breeding migration and summer movement of *Ambystoma maculatum*. Journal of Herpetology 17:176-177.

Klemens, M. W. 1993. Amphibians and reptiles of Connecticut and adjacent regions. State Geological and Natural History Survey of Connecticut Bulletin Number 112, New London, Connecticut, USA.

Madison, D. M. 1997. The emigration of radio-implanted spotted salamanders, *Ambystoma maculatum*. Journal of Herpetology 31:542-552.

Paton, P. W. C. 1994. The effect of edge on avian nest success: how strong is the evidence? Conservation Biology 8:17-26.

Paton, P. W. C., S. Stevens, and L. Longo. 2000. Seasonal phenology of amphibian breeding and recruitment at a pond in Rhode Island. Northeastern Naturalist 7:In press.

Petranka, J. W., M. E. Eldridge, and K. E. Haley. 1993. Effects of timber harvesting on southern Appalachian salamanders. Conservation Biology 7:363-370.

Petranka, J. W. 1999. Recovery of salamanders after clearcutting in the southern Appalachians: a critique of Ash's estimate. Conservation Biology 13:203-206.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12:1113-1119.

——— 2000. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management 64:615-630.

Shoop, C. R. 1965. Orientation of *Ambystoma maculatum*: movements to and from breeding ponds. Science 149:558-559.

SPSS, Inc. 1998. SPSS Base 8.0 Applications Guide. SPSS Inc., Chicago, Illinois, USA.

Stenhouse, S. L. 1985. Migration, orientation, and homing in *Ambystoma maculatum*. Copeia 1985:631-637.

Wilbur, H. M. 1980. Complex life cycles. Annual Review of Ecology and Systematics 11:67-93.

Windmiller, B. S. 1996. The pond, the forest, and the city: spotted salamander ecology and conservation in a human-dominated landscape. Dissertation. Tufts University, Boston, Massachusetts, USA.

Table 1. Overall capture rates (no. animals/100 trapnights) and percentage of metamorph amphibians at three arrays in southern Rhode Island from 1998-2000.

	Woods		Field		Railroad	
Species	Rate[a]	%meta[b]	Rate	%meta	Rate	%meta
American toad	1.43	51.7	0.44	41.3	0.44	4.2
Wood frog	4.03	68.5	0.12	76.0	0.02	100.0
Green frog	1.47	88.2	1.01	76.7	0.19	60.0
Bullfrog	0.01	0	0.05	27.3		
Pickerel frog	8.23	93.3	8.20	95.9	0.52	88.9
Gray treefrog	0.34	38.6	0.02	0	0.04	50.0
Spring peeper	6.61	6.3	0.45	5.3	0.12	0
Spotted salamander	0.70	47.0	0.34	94.3	0.04	100.0
Red-spotted newt	1.11	50.8	0.79	78.5	0.02	0
Red-backed salamander	3.68	1.4	0.35	1.4	0.08	0
Four-toed salamander	0.01	0	0.01	0		
Cumulative capture rate	27.62		11.78		1.47	46.1
Total no. trapnights	16,682		20,711		5,173	

[a]Number of immigrating and emigrating adults and emigrating metamorphs/100 trapnights.

[b]Percentage of captures that were metamorphs.

Table 2. Capture rates (no./100 trapnights) of emigrating and immigrating adult amphibians at 2 habitats near breeding ponds in southern Rhode Island,1998-2000.

	Immigrating					Emigrating				
	Forest-turf edge		Forest-interior			Forest-turf edge		Forest-interior		
Species	Mean	SE	mean	SE	P^a	mean	SE	mean	SE	P
American toad	0.202	0.045	0.732	0.153	<0.001	0.317	0.082	0.594	0.121	0.015
Wood frog	0.008	0.019	1.700	0.648	0.010	0.009	0.019	0.957	0.290	0.001
Green frog	0.202	0.067	0.213	0.061	0.885	0.087	0.037	0.130	0.045	0.459
Pickerel frog	0.461	0.095	0.941	0.289	0.072	0.202	0.064	0.123	0.052	0.317
Gray treefrog	0.008	0.023	0.210	0.065	0.008			0.204	0.064	0.002
Spring peeper	0.672	0.171	8.788	2.595	0.001	0.183	0.068	3.104	0.459	<0.001
Spotted salamander	0.001	0.001	0.479	0.182	0.010	0.009	0.017	0.228	0.066	0.004
Red-spotted newt[b]	0.144	0.046	0.817	0.207	<0.001	0.192	0.062	0.230	0.064	0.631

[a]Paired-t test of the hypothesis that animal capture rates were equivalent at forest- turf edge (Field array) and forest-interior (Woods array) during immigration to breeding ponds and emigration from breeding ponds, 547 df.

[b]Includes efts.

Table 3. Capture rates (no./100 trapnights) of emigrating juvenile amphibians in two habitats near breeding ponds in southern Rhode Island during 1998 and 1999.

Species	Forest-turf edge		Forest-interior		
	Mean	SE	*mean*	SE	P[a]
American toad	0.680	0.217	3.615	0.886	<0.001
Wood frog	0.340	0.101	11.046	2.282	<0.001
Green frog	2.882	1.007	4.822	1.146	0.123
Pickerel frog	29.180	8.505	28.176	10.404	0.874
Gray treefrog			0.557	0.165	0.001
Spring peeper	0.010	0.047	1.653	0.325	<0.001
Spotted salamander	1.182	0.323	1.248	0.467	0.869
Red-spotted newt	2.291	0.573	2.145	0.456	0.792

[a]Paired-t test of the hypothesis that animal capture rates were equivalent at forest-turf edge (Field array) and forest-interior (Woods array), 293 df.

Table 4. Percentage of metamorph spotted salamanders and wood frogs emigrating from Ponds #1 and #2 that were captured at Woods and Field arrays, Washington County, Rhode Island.

	1998			1999		
Species	No. at ponds[a]	No. at arrays[b]	% captured	No. at ponds	No. at arrays	% captured
Wood frog	1202	136	11.3	806	48	6.0
Spotted salamander	66	10	15.2	10	1	10.0

[a]Number of metamorphs that were captured and toe-clipped while emigrating from Ponds #1 and #2.

[b]Number of toe-clipped metamorphs that were captured at Woods and Field arrays.

Table 5. Number of frogs selecting a particular grass height for travelling after a 3-min trial experiment. Trials conducted only at night.

	Grass height					
	0.25"	0.5"	1.0"	>1.0"	*G*	*P*
Observed	14	29	21	29	3.7	0.29
Expected	23.25	23.25	23.25	23.25		

Table 6. Number of frogs selecting either woods or barren habitat when placed at the edge. Trials were conducted only at night.

	Habitat			
	Woods	Open	*G*	*P*
Observed	19	2	9.2	0.002
Expected	11.5	11.5		

Table 7. Number of frogs selecting either woods or turf habitat when placed at the edge. Trials were conducted only at night.

	Habitat			
	Woods	Turf	*G*	*P*
Observed	17	5	3.6	0.058
Expected	11	11		

Table 8. Total number of amphibians captured in potential travel corridors (forested habitats) or adjacent open corridors while migrating through a forested landscape on the URI campus.

	Forest	Open	*P*	Forest	Open	*P*	Forest	Open	*P*
American Toad	6	11	0.22	4	6	0.53	15	16	0.86
Green Frog	3		0.08	3	1	0.32	22	15	0.25
Gray Treefrog	2	2	1.0	8	7	0.80	31	14	0.01
Pickerel Frog	10	13	0.53	2	4	0.41	1063	559	<0.001
Red-backed Salamander	13	10	0.53	34	20	0.06	2	1	0.56
Spring Peeper	96	59	0.003	80	38	0.001	387	106	<0.001
Spotted Salamander	3	5	0.48	6	2	0.16	31	16	0.03
Wood Frog	23	7	0.003	35	16	0.008	1892	511	<0.001

Table 9. Total number of amphibians captured from 1997 to 2000 at Beaver River array adjacent to a golf course under construction (1999-2000). In 1997 and 1999, arrays were opened too late to capture all adults (see below*).

	Adults				Metamorphs			
Species	1997	1998	1999	2000	1997	1998	1999	2000
Am Toad	12	20	6	7	211	1177	106	109
Bullfrog	3	2	2		5	2	8	5
Green Frog	4	6	2	13	251	190	196	46
Pickerel Frog	1	3	1	1	5	36	18	1
Spring Peeper	1	9		13		1		
Wood Frog	82	911	5	144	216	186	36	842
Four-toed Salamander	1	1	1	1				
Two-lined Salamander	1							
Marbled Salamander	42	64	5	9	1357	57	19	2
Spotted Salamander	7	23		18	2	49	1	72
Red-backed Salamander	68	192	39	28	2	13	1	

*1997: opened 19 Mar to 25 Nov; 1998: opened 12 Feb to 29 Nov; 1999: opened 22 May to 30 Sept; 2000: opened 1 Mar to 19 Oct.

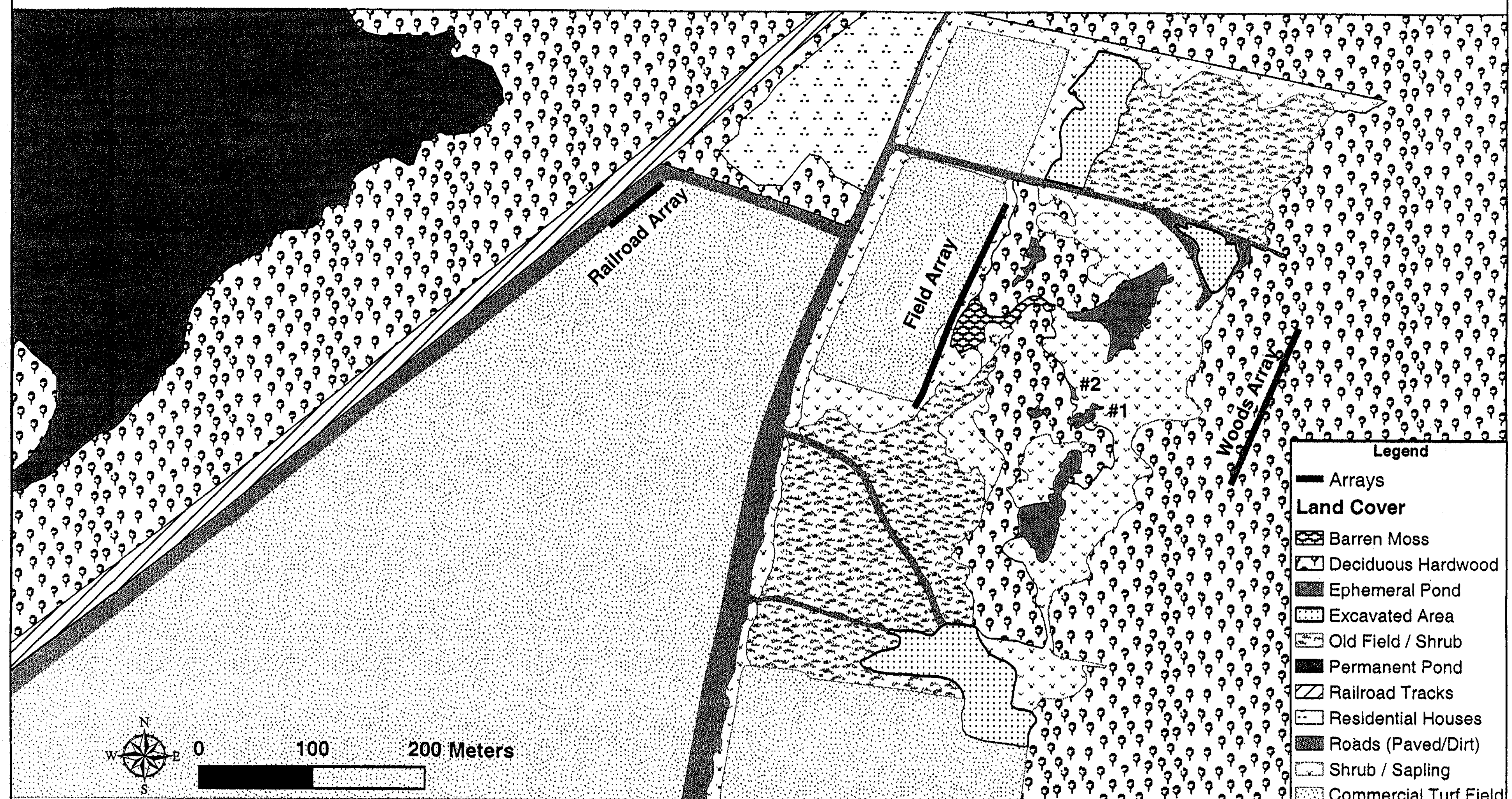

Figure 1. Location of drift fence arrays and amphibian breeding ponds monitored from 1998-2000 near the University of Rhode Island-Kingston campus.

Figure 2. Location of experimental forested travel corridors used during experiments in the 2000 field season.

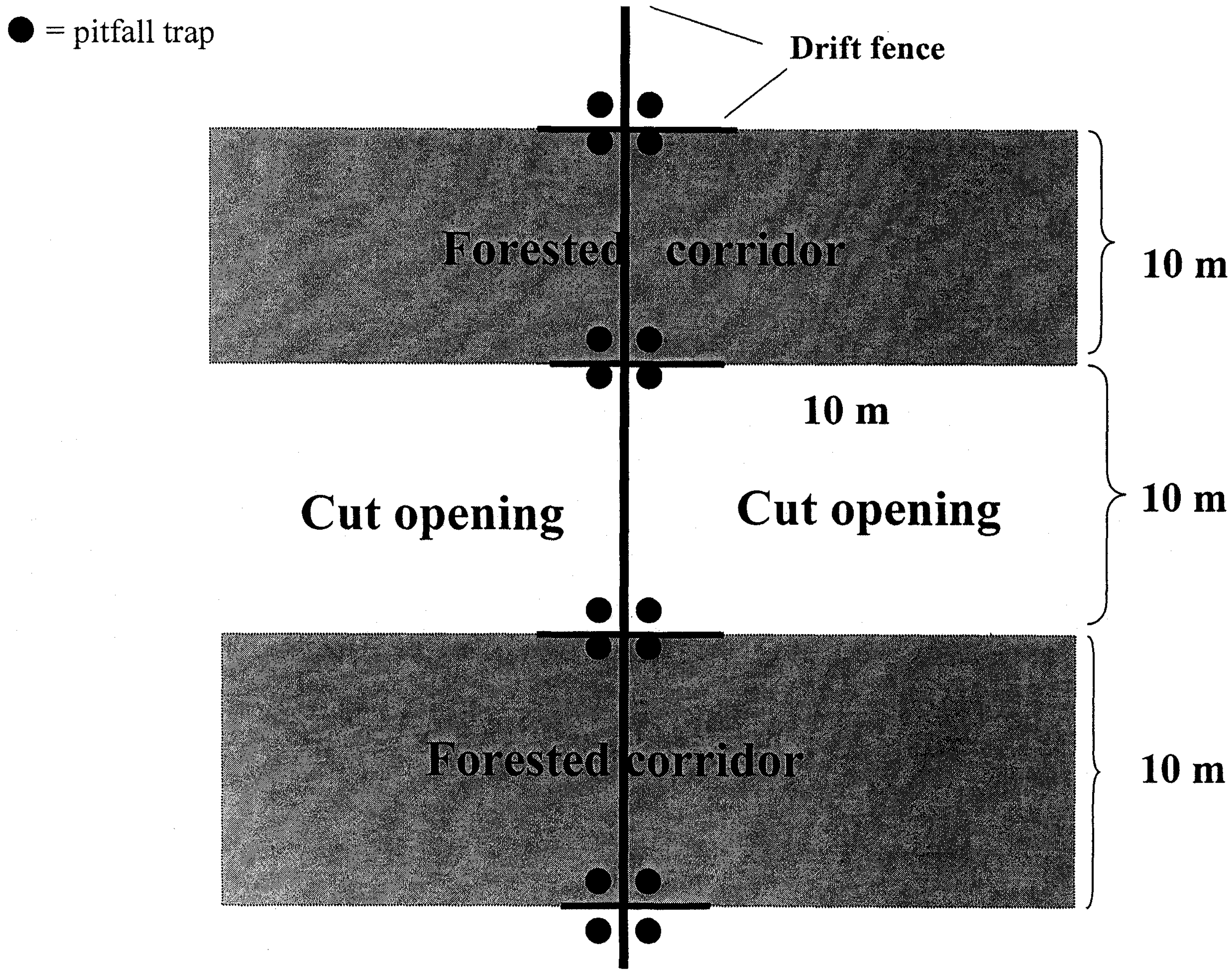

Figure 3. Diagram of layout for forested travel corridor experiments conducted during 2000 field season.

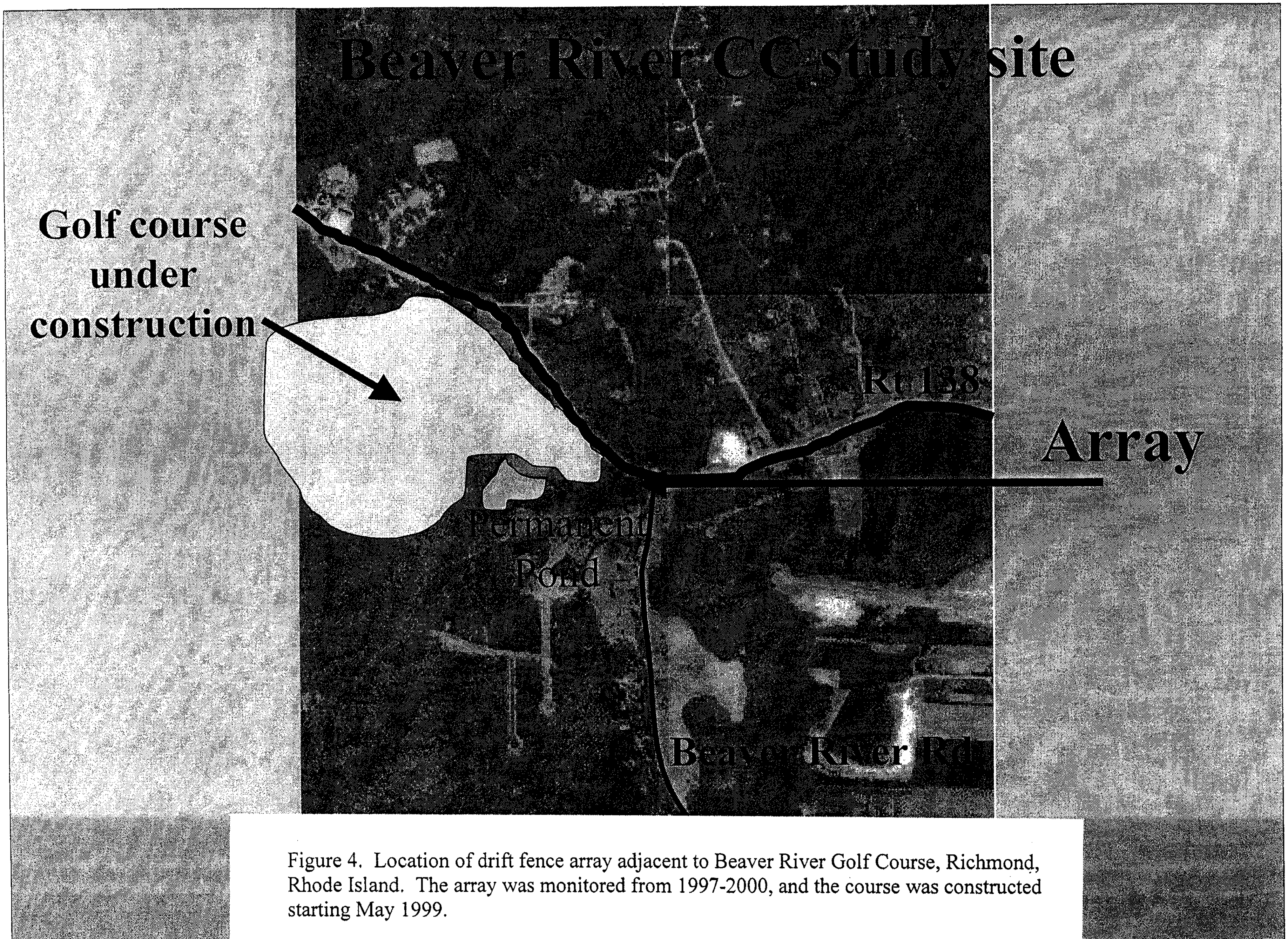

Figure 4. Location of drift fence array adjacent to Beaver River Golf Course, Richmond, Rhode Island. The array was monitored from 1997-2000, and the course was constructed starting May 1999.