THE ABUNDANCE AND DIVERSITY OF STREAM SALAMANDERS ON MONTANE GOLF COURSES

A Thesis Presented to

the Faculty of the Graduate School

University of Missouri-Columbia

In Partial Fulfillment

Of the Requirements of the Degree

Master of Arts

By

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DECEMBER 2012

The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

THE ABUNDANCE AND DIVERSITY OF STREAM SALAMANDERS ON MONTANE GOLF COURSES

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A candidate for the degree of Master of Arts

And hereby certify that in their opinion it is worthy of acceptance.

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ACKNOWLEDGEMENTS

My time at the University of Missouri has been a time of growth and transformation. I owe so much of my positive experience to Dr. Ray Semlitsch. He was able to mentor me and my labmates with patience and empathy while still pushing us to meet the potential he knew we each held. The example Dr. Semlitsch provided as he successfully conducted his research and teaching without compromising his integrity was invaluable for me.

I thank my committee members, Dr. Lori Eggert and Dr. Rose-Marie Muzika, for their guidance that has and will help me on my life track. I would also like to take the time to thank my undergraduate advisor and University of Missouri alumni, Dr. Michelle Boone. Dr. Boone shaped me during my formative years as a researcher at Miami University, and her first hand experience of the quality of Mizzou's biology department and Dr. Semlitsch's lab made my decision of where to attend graduate school quite simple.

I owe a special thanks to lab mate and friend Bill Peterman who educated me both in stream salamander identification and the ins and outs of life in Highlands, NC. My other labmates, Julia Earl, Michael Osbourn, Tom Luhring, Shannon Pittman, Grant Connette, Katie O'Donnell, Britt Ousterhout, and Tom Anderson have all contributed in their own unique way to create an unforgettable lab atmosphere. I look forward to these friendships lasting well beyond our "Missouri years."

I am thankful for the unwavering and unconditional support I enjoyed from my immediate and extended family back in Cincinnati, OH. One cannot really quantify or understand the positive effects that support system has on body, mind, and spirit. I'd like to thank my brother David Mackey whose curiosity about the nature and love of learning kept me always appreciative of my occupation. I owe my twin sister Tracy Mackey, a fellow biology researcher and concurrent graduate student, special thanks for bridging the sometimes distant gap between family and academia. Finally, I thank my parents for the decision to raise me and my siblings in a way that provided necessary discipline yet also promoted pursuing one's own passion. This has made my career as a graduate student much more fruitful.

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THE ABUNDANCE AND DIVERSITY OF STREAM SALAMANDERS ON MONTANE GOLF COURSES

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ABSTRACT

Stream salamanders are often the most abundant vertebrates in headwater streams and they play an integral role as both predators and prey in these ecosystems. Because they typically use both terrestrial and aquatic habitat and because of their susceptibility to a range of environmental disturbances, it is widely understood that stream salamanders are useful as biological indicators of ecosystem health. As a result, they have been increasingly incorporated into stream and watershed monitoring efforts. We conducted a study to examine how stream substrate complexity influences both capture rates and observed species richness of stream salamanders of two common sampling techniques, leaf litter bags and visual encounter surveys (VES). The goal of this study was to develop monitoring recommendations to optimize capture rates and species detection ability. We conducted this study at four first to second-order streams in the vicinity of Highlands, North Carolina. We found that catch per unit effort (CPUE) did not differ significantly between litter bag sampling and VES. Overall, we detected significantly more species in transects with complex substrate using both leaf litter bags and VES. Because different sampling techniques appear to target different ranges of species, we believe the use of more than one sampling technique may allow more accurate estimation of stream salamander abundances and species richness.

With over 22 golf courses located within a 20 mile radius of downtown Highlands, NC, it is clear golf is a significant land use in this region. Recent studies indicate golf courses may have a potential role in biodiversity conservation and management in human dominated landscapes, and may serve as a model for balancing human-use and conservation. To serve this role, effects of current golf course management practices must first be better understood. We monitored larval and adult stream salamanders in reaches located upstream, on, and downstream of managed areas of 10 golf courses in western North Carolina, USA. We measured in-stream and riparian habitat characteristics and tested for fertilizer and pesticide chemicals to explain trends in salamander abundances and diversity. Salamander abundance and diversity did not differ in stream reaches located upstream and downstream of managed areas on golf courses (i.e. fairways). Reaches located on managed areas contained lower abundances and less diverse stream salamander communities. Regression analyses and model ranking using the information-theoretic approach (AIC) revealed stream salamanders were positively impacted by increased riparian leaf litter depth and negatively impacted by increasing stream depth. Nitrate was not detected at any of the stream reaches and two of the 16 pesticide chemicals screened for were detected in negligible proportions. Our findings suggest golf courses in western North Carolina can currently provide viable habitat for stream salamanders in reaches upstream and downstream of managed areas of courses and may be enhanced through simple management practices such as leaf litter additions.

Chapter 1

MONITORING OF STREAM SALAMANDERS: THE UTILITY OF TWO SURVEY TECHNIQUES AND THE INFLUENCE OF STREAM SUBSTRATE COMPLEXITY

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Abstract

Stream salamanders are often the most abundant vertebrates in headwater streams and they play an integral role as both predators and prey in these ecosystems. Because they often use both terrestrial and aquatic habitat and because of their susceptibility to a range of environmental disturbances, it is widely believed that stream salamanders are useful as biological indicators of ecosystem health. As a result, they have been increasingly incorporated into stream and watershed monitoring efforts. The primary objective of this study was to determine how stream substrate complexity influences both capture rates and observed species richness of stream salamanders of two common sampling techniques, leaf litter bags and visual encounter surveys (VES), with the goal of developing monitoring recommendations to optimize capture rates and species detection ability. We conducted this study at four first to second-order streams in the vicinity of Highlands, North Carolina. We found that catch per unit effort (CPUE) did not differ significantly between litter bag sampling and VES. Overall, we detected significantly more species in transects with complex substrate using both leaf litter bags and VES. Because different sampling techniques appear to target different ranges of species, we believe the use of more than one sampling technique may allow more accurate estimation of stream salamander abundances and species richness.

Introduction

Stream salamanders are often the most abundant vertebrates in headwater streams (Peterman et al. 2008) and they play an integral role as both predators and prey in these ecosystems (Greene et al. 2008; Resetarits 1997). Because stream salamanders often use both terrestrial and aquatic habitat, they may be vulnerable to the degradation or contamination of either environment (Semlitsch 2000). As a consequence, stream salamanders have proven to be susceptible to terrestrial disturbances such as deforestation (Crawford & Semlitsch 2008; Johnston & Frid 2002) and aquatic disturbances such as siltation (Lowe et al. 2004) and stream acidification (Kucken et al. 1994). Because of this susceptibility to a range of environmental perturbations, it is widely believed that stream salamanders are useful as biological indicators of ecosystem health (Rocco & Brooks 2000; Welsh & Droege 2001). As a result, they have been increasingly incorporated into stream and watershed monitoring efforts (Jung et al. 2000).

A wide range of sampling techniques may be used to study stream salamanders, including active techniques such as dipnetting and visual encounter surveys (Grover 2006; Shaffer et al., 1994), or passive techniques such as funnel trapping or leaf litter bag sampling (Pauley 1995; Willson & Dorcas 2003). In this study, we examine the utility of two common techniques for monitoring stream salamanders: leaf litter bag sampling and nighttime visual encounter surveys (VES). The leaf litter bag refugia technique has long been used to sample aquatic invertebrates (Hilsenhoff 1969; Crossman & Cairns 1974), and has more recently been described as a method for surveying stream salamanders (Pauley 1995). Leaf litter bags may be ideal for many salamander monitoring efforts because they are inexpensive, non-destructive, easy to employ, and likely result in minimal observer bias (Chalmers & Droege 2002; Jung & Pauley 2003; Pauley & Little 1998; Waldron et al. 2003). Although leaf litter bags have been recommended for developing occupancy estimates for certain aquatic salamanders (Chalmers & Droege 2002; Pauley & Little 1998), this technique may be biased towards the larval and juvenile lifestages (Pauley & Little 1998). Furthermore, larval captures from litter bag sampling may be highly variable and may not demonstrate a clear relationship with actual abundances (Chalmers & Droege 2002; Waldron et al. 2003). Visual encounter surveys require relatively little equipment, are effective for a large range of species, and can be conducted across a wide range of habitats including terrestrial, riparian, and aquatic (Toft et al. 1982; Pough et al. 1987). However, visual encounter surveys may have variable results due to differences in capture rates between researchers (Heyer et al. 1994; but see Marsh 2009) and may yield results that are highly dependent on prevailing stream and weather conditions (Barr & Babbitt 2002; Heyer et al. 1994).

Another potential source of variation in stream salamander captures is the variability in stream substrate complexity that often exists at both a local and regional scale. A number of studies have demonstrated that the species richness of stream organisms is positively correlated with habitat complexity (Gorman & Karr 1978; Reice 1980; Schlosser 1982). In the southern Appalachians, larvae of many stream-dwelling salamander species frequently utilize leaf litter, rock cover, and interstitial spaces in gravel streambeds (Petranka 1998). As a result, variability in stream substrate complexity may influence both salamander abundance and species richness on a local scale, as well as the accuracy of abundance indices derived from capture data. For example, variability in leaf litter bag captures between sites may be at least partially explained by salamanders preferring litter bags no more than surrounding cover objects in areas of higher substrate complexity (Chalmers & Droege 2002).

Although there are several potential techniques for sampling stream salamanders, researchers may be limited by practical considerations such as time, resources, and the availability of surveyors. The primary objective of this study was to determine how stream substrate complexity influences both capture rates and observed species richness of stream salamanders of two common sampling techniques with the goal of developing monitoring recommendations to optimize capture rates and species detection ability. Specifically, we sought to compare 1) catch-per-unit-effort (CPUE) and observed species richness between sampling techniques and 2) CPUE and observed species richness between stream segments with low and high substrate complexity.

Methods

We conducted this study at four first to second-order streams in the vicinity of Highlands, North Carolina. The streams sampled were located within 8 km of the Highlands Biological Station (35.0323ºN, 83.1117ºW), (35.0312ºN, 83.1115ºW), (35º0317ºN, 83.1120ºW), (35.0209ºN, 83.1323ºW). At each stream, we surveyed two separate 10m transects; one with simple substrate and one with complex substrate. Although substrate complexity would typically be considered a continuous variable, we purposefully selected transects with either an extreme abundance or a complete lack of cover objects and treated substrate complexity as a dichotomous variable. Transects with complex substrate had >85% in-stream habitat cover (boulder, cobble, leaf litter, coarse woody debris), while those with simple substrate were entirely sandy or muddy with only sparse leaf litter for cover. At all four streams, the two transects were separated by a minimum of 50 m. Stream segments were selected by systematically searching 13 streams in the area around the Highlands Biological Station. The four streams included in this study were the only streams which met the aforementioned criteria of having: 1) a potential 10 m transect containing exclusively simple substrate and 2) a potential 10 m transect, at least 50 m from the first transect, containing complex substrate.

We constructed 40 leaf litter bags (Pauley & Little 1998) from 1.9 cm^2 polypropylene mesh. To create each leaf litter bag we filled 70 x 70 cm squares of netting with dry leaf litter, twisted the corners together, and cinched a cable tie around the joined corners. On 18 June, 2008 five leaf litter bags were systematically placed throughout each 10 m transect and were covered or surrounded by rocks to keep them in place in the stream. All bags were placed in at least 4 cm of water and were submerged to no more than three fourths of the bag's height.

Leaf litter bags were checked on 2, 16, and 30 July. During sampling, leaf litter bags were removed quickly from the stream and placed in a large white dishpan. As each bag was lifted from the water, a 15 x 20 cm baitnet was swept beneath it to capture any salamanders taking refuge underneath. Bags were held above the dishpan and shaken from side to side, dipped into the stream, and then shaken from front to back for a total of approximately 15 seconds. The water, sediment, and debris collected in the trays were then poured through the baitnet. The sediment and debris from the baitnet was then manually searched for salamanders. All captured salamanders were identified to species and then released within 1 m of the point of capture. We also conducted a time-constrained search (VES) for larval and adult salamanders at each transect in order to compare count data and observed species richness to those obtained with leaf litter bag sampling. Each 10 m transect was searched by two observers for a total of 30 minutes between 21:00 EST on August 4, 2008 and 02:00 EST on August 5, 2008. Salamanders were captured and identified to species and released in the stream.

With the goal of assessing techniques in terms of their ability to optimize capture rates during sampling efforts, we used our count data to compare the catch-per-unit-effort (CPUE) for each sampling technique. This capture rate is reported as the number of salamanders caught per hour of sampling. It is difficult to estimate total sampling time using leaf litter bags because they are in the water “sampling” for days or weeks before being checked. Therefore, the time we used to determine our capture rates is the total time spent by researchers actively sampling in the field. Leaf bags took 20 person minutes to check per transect, and 60 person minutes per transect for three days of sampling. One night of visual encounter survey took 60 person minutes per transect.

We analyzed total CPUE data using the ANOVA procedure of SAS (SAS® Version 9.1 for Windows, SAS Institute, Cary, NC, USA). We conducted a two-way nested ANOVA to examine the effect of substrate type (simple vs. complex) and survey technique (leaf bag vs. VES) on capture rates, while accounting for the fact that our true level of replication was at the stream level. We also conducted a repeated-measures ANOVA to examine the background variability in leaf litter bag capture rates over time. Finally, we ran an independent samples t-test to compare the mean number of species detected in simple and complex substrates.

Results

We captured a total of 690 salamanders, with leaf litter bag sampling accounting for 54% (N = 374) of total captures and VES accounting for 46% (N = 316) of total salamander captures. Larvae made up a majority of captures from both leaf litter bag sampling (89%) and VES (92%). The two techniques together detected every stream-affiliated salamander species known to be present at our study sites. We found that catch per unit effort (CPUE) did not differ significantly between litter bag sampling and VES ($F_{1,3}$= 0.21, p=0.6769). Catch per unit effort from both techniques combined did not show a significant relationship with substrate complexity ($F_{1,3}$= 1.61, p=0.2941). With leaf litter bag sampling, CPUE did not significantly differ across sampling occasions ($F_{1,8}$= 1.77, p= 0.2318).

Although CPUE was similar for both sampling techniques, leaf litter bag sampling and VES sampling differed slightly in the species they captured (Table 1). The two sampling techniques each accounted for roughly half of total salamander captures, yet litter bags captured a slight majority of *Desmognathus ocoee* individuals (61%), while nighttime VES captured a majority of *D. quadramaculatus* individuals (77%). In addition, we captured one *Pseudotriton ruber* metamorph and two *Gyrinophilus porphyriticus* larvae in leaf litter bags while neither species was detected at any site during VES. Both sampling techniques captured a large number of *Eurycea wilderae* larvae, while *D. monticola* was not commonly captured using either technique (Table 1).

Overall, we detected significantly more species in transects with complex substrate using both leaf litter bags (T_6= 2.954, p=0.025) and VES (T_6= 3.0, p=0.024; Fig. 1). Litter bag sampling detected a mean of 3.75 ± 1.26 SD species in transects with complex substrate and a mean of 1.75 ± 0.50 SD species in simple substrate. Using nighttime VES sampling we found a mean of 3.25 ± 0.96 SD species per transect with complex substrate and a mean of 2.00 ± 0.82 SD species per transect with simple substrate. Overall, surveying in complex transects tended to yield a higher observed species richness primarily because *D. monticola* and *D. quadramaculatus* were only frequently encountered around complex, rocky substrates (Table 1).

Discussion

Accurate estimations of amphibian abundances across time, locations, and observers require the use of standardized sampling methods and protocols (Heyer et al. 1994). Because substrate can be highly variable both within and between streams (Inoue & Nunokawa 2002; Vannote et al. 1980), it is important to determine whether this variability influences the efficacy of sampling techniques, particularly when using artificial refugia. Also, because certain sampling techniques may be inherently biased towards particular species or life stages while failing to detect others, any effect of stream substrate complexity on capture rates or observed species richness may significantly affect the utility of many survey techniques (Strain et al. 2008). Although we found no significant difference in CPUE between substrate types and between sampling methods, sampling in areas with greater substrate complexity revealed the presence of more species. For both sampling techniques, fewer species were found in areas of simple substrate than in areas of complex substrate. Stream salamander species have been shown to exhibit different substrate preferences, with *D. quadramaculatus* and *D. monticola* demonstrating a strong preference for rocky substrates (Southerland 1986). Although we found 3 *D. quadramaculatus* larvae in transects with simple substrate, the vast majority of *D. quadramaculatus* (19 of 22) and all *D. monticola* were found in transects with complex substrate (Table 1). These results are consistent with studies of other stream organisms where species richness has been found to be positively correlated with habitat complexity (Gorman & Karr 1978; Reice 1980; Schlosser 1982). Habitat complexity has repeatedly been shown to moderate predatory and competitive interactions (Babbitt & Tanner 1998; Crowder & Cooper 1982; Heck & Crowder 1991), and it has specifically been demonstrated that lotic habitat substrate complexity can decrease the susceptibility of larval salamanders to predation (Barr & Babbitt 2002). As a result, it seems likely that substrate complexity plays a critical role in sustaining high levels of salamander diversity and species richness in these headwater ecosystems.

This study demonstrates that leaf litter bag sampling and VES both have their strengths and weaknesses. Leaf litter bags are cheap, non-destructive, easy to employ, and likely result in minimal observer bias (Chalmers & Droege 2002; Jung & Pauley 2003; Pauley & Little 1998; Waldron et al. 2003). Leaf litterbags also take less time than nighttime VES sampling during repeated surveys and can be particularly useful for large scale inventories and when time-constrained sampling of individual sites is limited (Waldron et al. 2003). Although leaf litterbag sampling was relatively ineffective at capturing large body *D. quadramaculatus*, this technique did capture more *D. ocoee* than the nighttime VES technique. Further, *Pseudotriton ruber* and *Gyrinophilus porphyriticus* were only detected using leaf litter bags, which is consistent with other studies in which leaf bags effectively captured hard to detect species (Waldron et al. 2003). Visual encounter surveys are simple and require relatively little equipment. They are not as biased towards any particular life stage, and they can be implemented over a wide range of habitats. Because different sampling techniques appear to target different ranges of species, we believe the use of more than one sampling technique may allow more accurate estimation of stream salamander abundances and species richness. Following this recommendation, while considering the effects of stream substrate complexity on salamander diversity, can result in more effective stream salamander monitoring.

ACKNOWLEDGEMENTS

We thank J. Costa for permission to sample streams. Support for this project was provided by the Highlands Biological Station Fellowship. Salamanders were collected under North Carolina Wildlife Resources Commission permit number 08-SC00329. All procedures used in the study were approved by the University of Missouri Animal Care and Use Committee.

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Table 1. Total larval and adult salamanders captured by sampling technique and substrate type (*Leaf*=leaf litter bag, *VES*=visual encounter survey).

		Desmon	**Desoco**	**Desqua**	**Eurwil**	**Gyrpor**	**Pserub**
Leaf							
	larvae	0	0	4	328	2	0
	adults	5	19	1	14	0	1
	total	**5**	**19**	**5**	**342**	**2**	**1**
VES							
	larvae	0	0	13	278	0	0
	adults	7	12	4	2	0	0
	total	**7**	**12**	**17**	**280**	**0**	**0**
Complex							
	larvae	0	0	14	375	1	0
	adults	12	12	5	5	0	1
	total	**12**	**12**	**19**	**380**	**1**	**1**
Simple							
	larvae	0	0	3	231	1	0
	adults	0	19	0	11	0	0
	total	**0**	**19**	**3**	**242**	**1**	**0**

Desmon= Desmognathus monticola *Desoco*= Desmognathus ocoee *Desqua* = Desmognathus quadramaculatus *Eurwil*= Eurycea wilderae *Gyrpor*= Gyrinophilus porphyriticus *Pserub*= Pseudotriton ruber

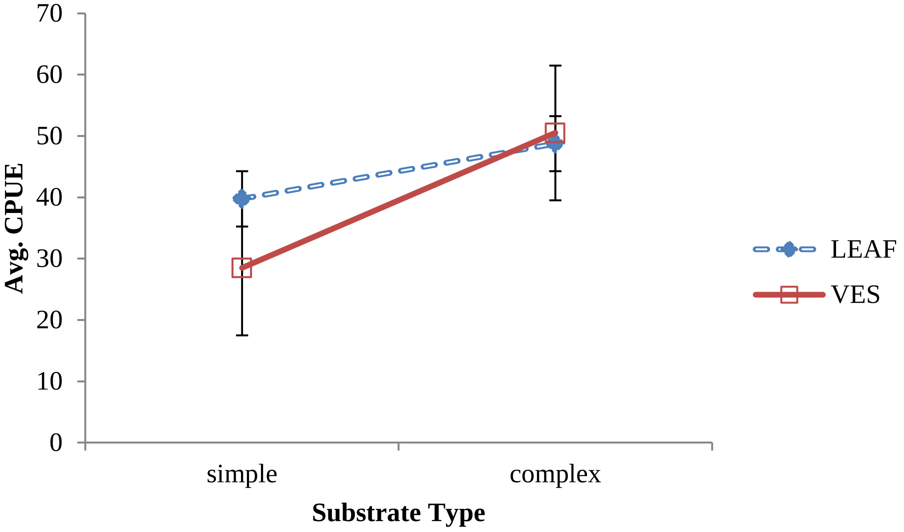

Fig. 1. Average catch-per-unit-effort (CPUE) using leaf litter bags (LEAF) and visual encounter surveys (VES) in simple and complex substrates.

Chapter 2

EXAMINING THE CONSERVATION VALUE OF GOLF COURSES: ASSESSING CURRENT MANAGEMENT IMPACTS ON STREAM SALAMANDER ABUNDANCE AND DIVERSITY IN THE SOUTHERN APPALACHIAN MOUNTAINS

Mark J. Mackey and Raymond D. Semlitsch

Abstract

Recent studies indicate golf courses may have a potential role in biodiversity conservation and management in human dominated landscapes, and may serve as a model for balancing human-use and conservation. To serve this role, effects of current golf course management practices must first be better understood. We monitored larval and adult stream salamanders in stream reaches located upstream, on, and downstream of managed areas of 10 golf courses in western North Carolina, USA. We measured in-stream and riparian habitat characteristics and tested for fertilizer and pesticide chemicals to explain trends in salamander abundances and diversity. Salamander abundance and diversity did not differ in stream reaches located upstream and downstream of managed areas on golf courses (i.e. fairways). Reaches located on managed areas contained lower abundances and less diverse stream salamander communities. Regression analyses and model ranking using the information-theoretic approach (AIC) revealed stream salamanders were positively impacted by increased riparian leaf litter depth and negatively impacted by increasing stream depth. Nitrate was not detected at any of the stream reaches and two of the 16 pesticide chemicals screened for were detected in negligible proportions. Our findings suggest golf courses in western North Carolina can currently provide viable habitat for stream salamanders in reaches upstream and downstream of managed areas of courses and may be enhanced through simple management practices such as leaf litter additions.

Introduction

Humans have dominated the global landscape (Vitousek et al. 1997) and habitat loss and alteration due to human land use is considered one of the biggest threats to biodiversity (Wilcove et al. 1998). Types of land use fall on a continuum of intensity ranging from severe (e.g. parking lot) to low impact (e.g. wilderness area). Despite the large breadth of this land use continuum, there has been a bias in conservation biology research towards areas of lesser human impact (Miller & Hobbs 2002). Although research in natural areas is undoubtedly crucial, nature reserves represent just a fraction of our global landscape (Scott et al. 2001). To be effective, conservation planning must be based on well designed studies along the entire spectrum of land uses, from the wild lands to areas where people live and work (Dale et al. 2000).

What are the contributions of urban nature reserves and other green amenity spaces, such as golf courses, to biodiversity conservation, and how can these be enhanced? This has been identified as one of the top scientific questions that, if answered, would have the greatest impact on conservation practice and policy (Sutherland 2009). Golf is a hugely popular and ubiquitous sport, with over 18,000 golf courses encompassing an estimated 2.7+ million acres in the United States alone (Baris et al. 2010). Consequently, any improvement or enhancement of management of natural areas on golf courses can result in widespread benefits.

Golf is a land use that is human centered yet seems to hold potential for biodiversity management (Gange & Lindsay 2002; Tanner & Gange 2005). A recent review suggests golf courses represent a promising measure for restoring and enhancing biodiversity in ecologically simplified landscapes (Colding & Folke 2009). Golf courses seem to hold potential to be designed and managed to promote ecosystem services while providing an opportunity for joint collaboration among conservation, restoration, and recreational interests (Colding & Folke 2009). Some recent studies have compared wetlands located on golf courses and nearby control-reference areas and provided evidence that golf courses can contribute to the support and conservation of amphibians and macroinvertebrates (Boone et al. 2008; Colding et al. 2009). Previous studies have been conducted in lentic systems (Boone et al. 2008; Colding et al. 2009; Harden et al. 2009), likely in part because ponds are often prevalent components of the golf course landscape. Streams are also abundant on golf courses. Lotic and lentic ecosystems can differ drastically, however, and it is imperative to get a better understanding of the effects golf course management can have on stream ecosystems and biodiversity. This is particularly important because stream networks connect golf courses to upstream and downstream systems.

Headwater streams specifically are estimated to account for at least 75% of the stream and river channel length in the eastern United States (Meyer & Wallace 2001). These headwater streams serve a number of important ecosystem processes including flood control, recharge of groundwater, recycling nutrients, maintenance of biological diversity, and sustenance for the biological productivity of downstream rivers, lakes, and estuaries (Meyer et al. 2003). Degradation and loss of headwaters and their connectivity to ecosystems downstream threaten the biological integrity of entire river networks (Meyer et al. 2007). Factors threatening the biodiversity of headwater streams are numerous, but habitat loss and degradation appear to rank highest (Allan & Flecker 1993). A number of potential negative effects can occur as a result of golf course management, including stream channelization, reduced riparian vegetation, elevated water temperatures, runoff of pesticides or fertilizers, and stream sedimentation (Klein 1990). All of these impacts can lead to habitat homogenization (Rahel 2002), which is one of most serious threats to the persistence of natural communities (Cardinale et al. 2002).

Salamanders are especially prolific in headwater streams of eastern North America where they are the most abundant vertebrate organism (Burton & Likens 1975; Peterman et al. 2008). Because they are highly philopatric, long lived, and live in relatively stable populations, stream salamanders may be more appropriate and reliable indicators of biodiversity and habitat quality in stream ecosystems than fish or macroinvertebrates (Welsh & Ollivier 1998). Stream salamanders may also be useful indicators of ecosystem health because they are adversely affected by deforestation and physical disturbance (Orser & Shure 1972; Petranka & Smith 2005; Willson & Dorcas 2002), siltation (Lowe et al. 2004; Welsh & Ollivier 1998), and stream acidification (Kucken et al. 1994).

The goal of our study was to assess the impact of current golf course management practices on stream salamanders by examining: 1) the effects of golf course management on stream salamander abundance and diversity, 2) the influence of in-stream and riparian habitat characteristics on salamander abundance and diversity, and 3) the presence and extent of chemical contaminant runoff from pesticide and fertilizer use. We predicted stream reaches located on and downstream of golf courses would contain fewer salamanders and less diverse assemblages than stream reaches located upstream of golf courses. We hypothesized this would be associated with decreased water quality and altered habitat characteristics due to direct and indirect effects of golf course management practices.

Methods

Study Area

Our study was conducted on 10 golf courses in the southern Appalachian region of western North Carolina, USA. All courses were located within a 30 km radius of Highlands, North Carolina. To examine the effects of golf course management practices on stream salamanders, we sampled three stream types on the basis of relative location to the course. UP-course reaches are those that occur upstream of a golf course and are characterized by intact habitat that does not experience direct effects of golf course maintenance (e.g. pesticide and fertilizer application, mowing, UV exposure, etc). ON-course reaches run directly through a golf course (perpendicular to the fairway) and experience direct chemical and physical effects of golf course maintenance practices. DOWN-course reaches are those that drain an actively managed portion of the golf course and potentially experience indirect effects of golf course maintenance such as increased water temperature, pesticide and fertilizer runoff, sedimentation, but do not experience direct physical habitat alteration. Two of each stream type were sampled on each golf course, totaling 6 transects per course and 60 overall stream reaches. All sampling transects were 25 m in length and all stream locations (DOWN, ON, UP) were located on separate streams. If transects of different stream locations were located on the same stream by necessity, they were separated by a minimum of 50 m.

Studies focusing on a single life stage cannot fully elucidate the response of populations to changes in the environment (Price et al. 2010), therefore we focused sampling methods on both larvae and adult salamanders. We used a modified technique of the leaf litter bag design to sample in-stream larval and newly metamorphosed salamanders (Pauley & Little 1998). Leaf bags were constructed by filling a 70 x 70 cm square of 1.9 cm mesh with deciduous leaves. Five bags were evenly distributed across each transect with 30 leaf bags deployed at each course and a total of 300 bags across all 10 golf courses. We checked leaf bags during daylight hours three times throughout the field season (May, June, July 2009). Bags were checked by shaking them over a 40 x 30 x 8 cm white tray. All captured salamanders were identified to species, measured to the nearest mm for snout-vent length (SVL), and released at site of capture.

To sample adult salamanders, the stream bank adjacent to each 25 m aquatic transect was searched at night three times during the activity season (June, July, August 2009). We used a visual encounter search (VES) during the three sample periods to capture surface-active salamanders. Two people simultaneously searched the area 2.5 m from the stream, one person on each bank, for a total of 20 min. As salamanders were captured, they were placed in sealable plastic bags until the 20 min had expired. At the end of each survey all salamanders were released at the site of capture.

Habitat measurements

We measured habitat variables at each of the 60 stream reaches in our study three times (May, June, July 2009). In the riparian area adjacent to each stream we measured soil moisture, soil temperature, leaf litter depth, leaf litter mass, ground surface temperature, percent canopy cover, and width of unmown buffer. In the wetted portion of the stream we measured water temperature, dissolved oxygen, percent sedimentation, surface water velocity, substrate composition proportions, qualitative estimates of cover rocks, and qualitative estimates of coarse woody debris levels. Values were averaged at each sampling period and later averaged across the three sampling times. All terrestrial measurements were taken approximately 1.5 m from the stream bank.

We measured percent canopy coverage from the center of the stream reach using a spherical crown densitometer measured in the four cardinal directions. We estimated stream width by measuring the wetted width of the stream at four locations approximately 6 m apart to the nearest 0.01 m. Percent sedimentation was quantified as the surface sediment covering the streambed, and was measured using a 50 X 50 cm quadrant that was divided into 25- equal sized square sections. We also used this method to quantify percentages of conglomerate, pebbles, and sand in the stream bed. Stream depth was measured to the nearest cm midstream at four locations approximately 6 m apart. We measured leaf litter depths to the nearest cm from two locations approximately 8 m apart on each side of the stream using a hand ruler. Stream temperatures, dissolved oxygen, and conductivity were measured from the center of each stream reach using a handheld YSI 85 meter. We measured pH using an Extech ExStik® meter from the center of the stream reach. Stream surface velocity was obtained using the float method (Gordon et al. 1992) at four locations in the stream approximately 6 m apart. A small fishing bobber was dropped into the stream and the time (sec) taken to float one meter was measured using a meter stick and a stop watch. We estimated leaf litter mass by measuring the wet-weight of drained leaf litter and other organic debris collected within a 0.25 m2 area at the aquatic-terrestrial interface using a 2 kg Pesola® spring scale. Coarse woody debris was visually estimated on a five point scale with 0 defined as no coarse woody debris and 4 defined as extensive woody debris spanning the width of the stream. We measured ground surface temperature using an infrared thermometer from two locations approximately 8 m apart on both sides of the stream. We measured soil temperature to the nearest 0.1°C from two locations approximately 8 m apart on both sides of the stream using a soil temperature probe. Buffer length was measured as the straight line distance from the center of the stream transect to the nearest managed area of the golf course to the nearest m. Soil moisture was obtained by collecting soil samples from two locations approximately 8 m apart on both sides of the stream using a hand shovel. Samples were placed and sealed into zip loc bags and returned to the laboratory. Samples were placed into labeled brown paper bags and weighed to the nearest 0.01 g. Samples were then dried in a soil oven at 35°C for 24 hours and were again weighed to the nearest 0.01 g. We calculated percent soil moisture for each sample using the equation: 100 X [(wet wt. - dry wt.)/(dry wt.)].

Nitrate and pesticide testing

Because of the potential for nitrate to adversely affect amphibian survival (Rouse et al. 1999) we tested water samples from each stream reach for the presence of nitrate from 15 June to 26 June. A 25 ml water sample was collected from the center of each stream transect and returned to the laboratory the same day for testing using a LaMotte TesTab reagent test kit for nitrate/nitrogen (range 0-15 ppm; minimum detection range 1 ppm) . We tested for the presence of pesticides in leaf litter rather than water because salamanders of all age classes spend considerable time in contact with leaf litter and because leaf litter is likely to remain stationary longer than water in lotic systems (Mississippi State Chemical Laboratory, personal communication). We collected a one quart leaf litter sample from 27 July to 7 August from the center of each of the 20 DOWN-course stream reaches and from 6 randomly chosen UP-course reaches from pre-deployed leaf bags. Samples were collected and sealed into freezer-durable plastic bags and frozen immediately upon returning from the field. Prior to sample collection, we obtained a list of the top used pesticides (fungicides, herbicides, and insecticides) from the 10 golf course superintendents in order to compile a list of regionally applied pesticides of which to screen during analyses. Samples were sent to Mississippi State Chemical Laboratory (Mississippi State, MS, USA) for chemical analyses. “QuEChERS” was used for determination of pesticides residues in the leaf litter samples (Anastassiades et al. 2003).

Data analyses

To compare UP-, ON-, and DOWN-course streams we used mean abundance and mean diversity indices from leaf bag captures (larvae and metamorphs) and from VES (adults) captures. For species diversity, we calculated the Shannon–Weiner index [$H' = -\Sigma(pi \ln pi)$], where pi is the proportional abundance of species i. Species proportions used in calculating the diversity indices were obtained from the total abundances. For both leaf bag and VES captures, one-way analysis of variance (ANOVA) was conducted to test for significant differences of total salamander abundances and salamander diversity among the three stream locations (UP-, ON-, and DOWN-course). We used Tukey's honest-significance- difference test for pairwise comparisons of locations.

We used regression models to examine the relationship between stream salamander abundance and diversity to habitat characteristics. Due to the differences in habitat preference of larvae and adult salamanders, it was necessary to run separate models for leaf bag and VES captures. We based habitat variable selection on previous studies and observations (Table 1). Predictor variables were examined for correlation using Spearman correlation coefficients and were excluded from regression analyses if highly correlated ($|r| > .70$; Welsh & Lind 2002). We also set a minimum correlation value of 0.20 between the predictor variable and the response variable. A resulting seven habitat variables were used singly and in combination in the final regression models for leaf bag captures and six habitat variables in the VES models (Table 2).

Regression models with a normal distribution were developed using the generalized linear model in SPSS version 17.0 (SPSS Chicago, Illinois). We developed biologically relevant combinations of the non-correlated environmental variables including the global model containing all predictor variables, combinations of variables, single variables as models, and null-intercept only models (Table 2; Table 3). Overall we created 12 *a priori* models testing hypotheses predicting abundance and diversity from leaf bag captures and 11 *a priori* models predicting abundance and diversity of VES captures. We based *a priori* models selection on published literature as well as observations and pilot data collected in 2008.

To rank models assessing salamander diversity in relation to habitat characteristics, we used Akaike's Information Criterion. For each model, we calculated the AIC_C value, which is the measure of strength of evidence for a given model adjusted for small sample size. We then measured the ΔAIC_C for each model, which is the difference in AIC_C between each model and the best model in the set. A ΔAIC_C less than 2 suggests that there is substantial support for the model, a ΔAIC_C between 3 and 7 suggests that there is considerably less support for the model, and a ΔAIC_C greater than 10 suggests that the model is very unlikely to best explain reality (Burnham and Anderson 2002). We also calculated Akaike weights ($\omega_{i)}$, which represent the probability that the given model is the best among the entire set of candidate models (Burnham & Anderson 2002).

To account for overdispersion of salamander abundance data (leaf bags $\hat{c} = 1.98$; VES $\hat{c} = 2.31$), we used Quasi Akaike's Information Criterion ($QAIC_C$; Burnham & Anderson 2002) for selection of abundance models. We used model averaging and unconditional variance estimation to assess the contribution of individual habitat variables to the models' predicting power. This can be particularly informative when ω_i values are low and when there is no clear top model among the set of candidate models.

Results

Total Captures and Species Detections

A total of 2,215 salamanders were detected across all transects throughout the summer of 2009. Of this total, 1,015 salamanders were caught during leaf litter bag sampling and 1,200 were caught during nighttime VES. Throughout the field season we detected nine salamander species: Seal salamander (*Desmognathus monticola*), Ocoee salamander (*Desmognathus ocoee*), Black-bellied salamander (*Desmognathus quadramaculatus*), Blue Ridge two-lined salamander (*Eurycea wilderae*), Three-lined salamander (*Eurycea guttolineata*), Red salamander (*Pseudotriton ruber*), Spring salamander (*Gyrinophilus porphyriticus*), Grey-cheeked salamander (*Plethodon metcalfi*), and Red-spotted newt (*Notophthalmus viridescens*). *N. viridescens* occurred infrequently and was only captured during VES and was therefore omitted from analyses. *P. metcalfi*, although caught frequently during VES of riparian habitat, was also omitted from analyses because it is strictly a terrestrial species and was not captured by leaf litter bags.

Comparison of Stream Locations

There was no significant difference in abundance of larval and metamorph captures between the three stream locations (F = 1.675, df = 2, 57, p = 0.196; Fig. 1). There was a significant difference in diversity indices of larvae derived from leaf bag totals (F = 6.140, df = 2, 57, p = 0.004; Fig. 1). The ON-course streams had significantly lower diversity than the UP-course (-46.7%; Tukey's HSD test, p=0.004; Fig. 1) and the DOWN-course (-42.7%; Tukey's HSD test, p=0.033; Fig. 1). Salamander diversity of the UP-course streams and the DOWN-course streams did not differ significantly (Tukey's HSD test, *p*=0.725; Fig. 1).

There was a marginal difference in mean adult and juvenile captures between the three stream locations (F = 2.651, df = 2, 57, p = 0.079; Fig. 2), and mean ON-course captures were notably lower than UP-course (-44%; Tukey's HSD test, *p*=0.138) and DOWN-course (-45.5%; Tukey's HSD test, *p*=0.110) streams. There was no significant difference in diversity indices of adults and juveniles derived from VES captures between the three stream locations (F = 6.197, df = 2, 57, p = 0.310; Fig. 2).

Habitat Variables

Of the eleven *a priori* models predicting larval and metamorph abundances, the Leaf model consisting solely of the leaf depth variable was the most supported (ω_i= 0.464; Table 3). This can be interpreted as the Leaf model has a 46.4% probability of being the best predictive model among the set of candidate models. Leaf depth had a positive effect on larval abundances and was the only significant parameter estimate for abundances obtained from the model averaging (Table 4). The *a priori* model best explaining larval diversity was the Bed Retention model, which consisted of the leaf depth and stream depth parameters (ω_i= 0.438; Table 3). Stream depth had a strong negative association with larval diversity and leaf depth had a relatively small positive association with diversity (Table 4). Although the buffer parameter's confidence intervals did not overlap zero, the parameter estimate was miniscule.

Of the twelve *a priori* models predicting juvenile and adult abundances, all of the top models had low model weights (Table 3). Of the competing models, the Soil moisture model which included only the soil moisture parameter had the greatest support (ω_i=0.276; Table 3). Soil moisture was positively associated with adult abundance and was the only parameter estimated with a confidence interval that did not overlap zero (Table 4). The *a priori* model best explaining juvenile and adult diversity was the Stream model, which consisted of the stream depth and cover rocks parameters (ω_i= 0.792. Table 3). Cover rocks were positively associated with adult diversity whereas stream depth was negatively associated with adult diversity (Table 4).

Pesticides and Nitrate

Nitrate was not detected at or above the minimum detection range (1 ppm) in any of the water samples taken from the 60 stream reaches during the summer in this study. Of the 16 chemicals tested for, only Propiconazole and 4OH-Chlorothalonil were detected. Propiconazole, an active ingredient of a fungicide, was detected in 8 of the 20 DOWN-course streams and had an average detection proportion of 0.0135 ppm. 4OH-Chlorothalonil, a breakdown product of the fungicide active ingredient Chlorothalonil, was detected in 9 of the 20 DOWN-course reaches with an average detection proportion of 0.0162 ppm and was also detected in one of the UP-course streams (Table 5).

Discussion

Our hypothesis that stream reaches located downstream of golf courses would provide decreased in-stream and riparian habitat quality and thus fewer and less diverse salamander populations was not supported by our field data. Our finding of no significant difference in stream salamander abundances and species diversity immediately upstream and downstream of actively managed areas of golf courses suggests habitat quality for stream salamanders at our sites is not compromised due to golf course maintenance. All stream reaches sampled were located on golf course property, and our results indicate some stretches of golf course streams can provide viable habitat for stream salamanders. The ON-course stream reaches, those which flow directly through fairways and actively managed areas of golf courses, did contain lower abundances and less diverse stream salamander communities. Though we did not include any off-site control streams in our study, data from a previous study in nearby national forest streams were available for comparison. The average *E. wilderae* larvae captures per sampling period in our UP-course (1.04 larvae/bag) and DOWN-course (0.83 larvae/bag) reaches fall within the range reported from control reaches in a study conducted in nearby (~50km) Nantahala National Forest (control 1, 2006: 0.67 larvae/bag; control 1, 2007: 0.71 larvae/bag; control 2, 2007: 2.22 larvae/bag; (Peterman & Semlitsch 2009). Five stream-associated species were detected at these control sites between 2004-2007 (Peterman 2008); seven stream-associated species were detected at each of our three stream types (UP-, ON-, and DOWN-course) in the summer of 2009. The two species detected on golf course properties and not detected at the national forest sites were *P. ruber* and the *E. guttolineata*.

Although golf has often received negative attention in the past due to chemical pesticide and fertilizer use (Baris et al. 2010), the results of pesticide and fertilizer tests from our study indicates this is not the foremost issue at our study streams. Propiconazole was detected at an average concentration of more than 30 times below the U.S. Environmental Protection Agency (EPA) maximum allowable concentration (0.425

ppm; Baris et al. 2010). 4OH-Chlorothalonil, a breakdown product of the fungicide active ingredient Chlorothalonil, was detected at levels more than 900 times lower than toxic concentrations. Lotic systems are characterized by flowing water and chemical analyses of lentic or stagnant waters may yield different results. Our chemical analyses were, however, taken from leaf litter samples which are more likely to remain in place than water samples (Mississippi State Chemical Laboratory, personal communication). Although our chemical tests were relatively extensive, it should be noted that the presence or absence of a chemical reported from our analysis refers only to the time the sample was collected, not the entire duration of the study. Likewise, the timeframe of the entire study is just a snapshot in time that may not accurately depict trends in nitrate and pesticide levels over longer timeframes. A study examining the nutrient discharge of five coastal North Carolina golf courses reported courses to have generally greater nitrate levels leaving the courses compared to entering the courses, but the concentrations varied greatly among courses (Mallin and Wheeler 2000). Though the contamination of water bodies from golf course maintenance should still be considered a potential concern, our findings are consistent with a large-scale review in the United States which found no significant human toxicological impacts from golf courses to groundwater and surface water (Cohen et al. 1999). A recent study updated and expanded this database to include all golf course water quality data meeting review criteria over a 20 year period (Baris et al. 2010). The study reports that pesticide levels exceeding surface and ground water quality criteria were rarely observed. Total phosphorous, which was added to the database, appeared to be the analyte of greatest concern in surface waters. This result was published after the onset of our study. Intense public scrutiny has led to great improvements in turf science and pesticide regulations since the early 1990's (Baris et al. 2010), and continued care must be taken to ensure pesticide and fertilizer use does not compromise non-target organisms.

Streams located directly on fairways contained lower abundances and less diverse stream salamander communities. This result was predicted considering riparian vegetation of streams located in actively managed areas on golf courses is often greatly reduced or completely replaced by turf grass. Streams can be subjected to a number of alterations from human land use such as sedimentation, nutrient enrichment, hydrologic alteration, riparian clearing/canopy opening, and loss of woody debris (Allan 2004), all of which can lead to increased habitat homogeneity (Rahel 2002). Because of stream salamanders' life histories, physiology (Southerland et al. 2004) and because of their sensitivity to alterations of microhabitat (Welsh and Ollivier 1998), we did not expect to capture as many individuals in streams on fairways as were captured throughout this field season (270 juveniles/adults, 238 larvae). The availability of colonizers is an important consideration for stream management and restoration efforts (Bond & Lake 2003). In the absence of active introductions, colonization of restored habitat is entirely reliant upon the dispersal of organisms from extant populations (Bond & Lake 2003). Our results indicate stream salamanders are currently present in streams located on golf courses, albeit in lower abundances, as well as populations present in upstream and downstream reaches that could provide potential colonizers for future stream restoration efforts.

Our analysis of in-stream and riparian habitat characteristic as predictors for stream salamander abundances and diversity provides a step toward active stream management efforts to mitigate undesirable anthropogenic impacts and improve stream habitat on golf courses. Our AIC regression analysis found leaf litter to be an important predictor for salamander abundances. It has long been documented that leaf litter input is the most important basal energy source in shaded headwater streams (Vannote et al. 1980). This coarse particulate organic matter is colonized by microbes which then become a food source for feeding groups of aquatic macroinvertebrates (Cummins 1974). Macroinvertebrates are eaten by other predatory insects and fish (Cummins 1974) as well as salamanders (Petranka 1998). Leaf litter both sustains a critical food source for salamanders (Johnson & Wallace 2005; Johnson et al. 2006) and provides necessary refugia for salamanders of all life stages (Crawford & Semlitsch 2008; Petranka 1998). Reduced standing stock of organic matter is often a consequence of human land use and can result in a reduction of a stream's capacity to intercept nutrients (Meyer et al. 2005). Golf courses specifically have reduced detritus sources due to removal of non-turf vegetation for tee boxes, fairways, and greens. Leaves and dead plant matter remaining on courses are removed for aesthetic purposes through routine course maintenance. Average leaf litter depth at the aquatic-terrestrial interface was 97% shallower in our ON-course reaches than in our DOWN and UP-course reaches (UP: 3.38 cm; ON: 0.09 cm; DOWN: 3.10 cm). Incorporating leaf litter into future golf course management could improve the food source and habitat for aquatic organisms as well as improve nutrient retention and water quality for both on course and downstream communities (Aldridge et al. 2009). The authors are currently experimentally testing the effects of increased stream detritus retention on macroinvertebrate and larval salamander communities through coarse woody debris additions (Mackey & Semlitsch, unpublished data). We encourage other researchers to test the utility of this potential management method in other regions to better understand its ecological effects on stream communities and the breadth of its application (contact authors, see Hall & Fleishman 2010).

We found buffer length and stream depth to be top predictors of stream salamander diversity. Riparian buffer strips adjacent to stream have been used in managed forests for more than two decades (Vesely & McComb 2002), and they can mitigate effects of human land use such as chemical runoff, siltation, and increased water temperatures (Jones et al. 1999; Lowrance et al. 1984; Vesely & McComb 2002). Stream salamanders typically inhabitat clear and relatively shallow waters (Sih et al. 1992). Increases in stream width and depth have been found to accompany urbanization (Galster et al. 2008), as well as an effect on stream biota that is analogous to increasing stream order (Barrett & Guyer 2008). This loss of low-order stream habitat and its associated stream biota allows riverine species to move further up the stream network and decrease stream network heterogeneity.

The data collection for this study occurred over one field season and in one particular region of the U.S. We focused on one taxonomic group and one type of aquatic system. These limitations were a necessary tradeoff for the intensity and area of sampling conducted. This study involves more golf courses than any previous single study conducted on golf courses globally and included a total of 60 stream stretches sampled six times. Additionally, the Highlands-Cashiers, NC region represents an area that is not urbanized, is largely forested, and is adjacent to large natural areas (national parks). A review by Colding and Folke (2009) found the ecological value of golf courses significantly increases with lands that have high levels of anthropogenic impacts and significantly decreases with lands that have low anthropogenic impacts, such as natural and nature-protected areas. However, it is also possible salamander populations from surrounding forested landscapes provide a source that would not be available in urbanized landscapes.

The impact of habitat destruction can be mitigated through outright habitat protection, but the increasing human population limits the feasibility of this solution (Boone et al. 2008). Considering ecological premises are more widely accounted for in golf course design and management, courses could increasingly become an asset in ecosystem management and biodiversity conservation (Colding et al. 2009) and serve as models for ecological awareness and sustainability. With an estimated 27.1 million golfers in 2009 in the U.S. alone (NGF 2010), conservation integration to the game has the capability of reaching a large audience that otherwise may not be exposed to conservation concepts and practices. Golf courses can serve as opportunities for demonstration, the translation of scientific understanding into metrics of performance and cost under real world conditions, that is key in the progression of fundamental research to applied science (Hall & Fleishman 2010). Management techniques developed for golf courses can also potentially be used in similar systems such as state parks, cemeteries, historical sites, and a number of other human land uses. As the golf industry becomes more open to land stewardship, sustainability, and ecological awareness, a valuable opportunity is provided for researchers to collaborate with this group of managers and provide constructive science-based guidelines for improvement.

Acknowledgements

We thank G. Connette, D. Mackey, and D. Riegel for assistance in the field and the Highlands Biological Station staff for use of facilities. We appreciate the valuable comments from G. Connette, A. Cox, J. Earl, and W. Peterman on early versions of this manuscript. We owe a special thanks to the superintendents and managers of the 10 participating golf clubs whose volunteered support and accommodation made this study possible. This research was partially supported by a Highlands Biological Station Fellowship to M.J.M and a United States Golf Association and National Fish and Wildlife Foundation's Wildlife Links granting program to M.J.M. and R.D.S.

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Table 1. Description and justification of single parameters used in *a priori* regression models predicting stream salamander abundance and diversity.

Parameter	*Description*	*Justification*
Sediment	Percent sedimentation of stream bottom	Can negatively impact larval stream salamanders (Peterman & Semlitsch 2009)
Sand	Percent sand of stream bottom	Fewer species are detected in reaches with homogenous substrate (Mackey et al. 2010)
Water temperature	Water temperature of stream	Can influence length of larval period (Voss 1993)
Stream width	Width of wetted portion of stream	May affect leaf litter deposition and stream substrate characteristics (Peterman & Semlitsch 2009)
Stream depth	Depth of stream	May affect water flow rate and microhabitat characteristics (Peterman & Semlitsch 2009)
Buffer	Width of unmown or forested buffer between stream and managed area	Affects sediment influxes into streams, water temperatures, allochthonous inputs, and riparian microclimate (Peterman & Semlitsch 2009)
Soil temperature	Temperature of soil	Can influence stream salamander abundance and microhabitat use (Crawford & Semlitsch 2008)
Leaf depth	Depth of leaf litter located within 1m of stream	Primary nutrient source in allochthonous-based headwater streams and important for salamander refugia (Crawford & Semlitsch 2008)
Soil moist	Percent moisture of soil located within 1m of stream	Can influence stream salamander abundance and microhabitat use (Crawford & Semlitsch 2008)
Cover rocks	Qualitative estimate of rocks providing suitable salamander refuge	Are used as protective cover and nesting sites and therefore are strongly correlated with salamander density (Davic & Orr 1987)
Coarse Woody Debris	Qualitative estimate of in-stream wood	May provide refugia as well as nutrient source for salamander prey (Peterman & Semlitsch 2009)
Dissolved Oxygen	Percent dissolved oxygen in stream	Has been suggested to be a factor limiting stream salamander abundances (Willson & Dorcas 2002)

Table 2. *A priori* regression models used in the prediction of abundance and diversity of larvae and metamorph captures and adults and juvenile captures.

		Model name	*Model terms*
Larvae and metamorphs			
	Abundance models		
		Null	NA
		Buffer	Buffer
		pH	pH
		Sediment	Sediment
		Stream depth	Stream depth
		Leaf depth	Leaf depth
		CWD	CWD
		D.O.	D.O.
		Water Quality	D.O., pH
		Retention	CWD, leaf depth
		Peterman	Buffer, sediment
		Global	All variables
	Diversity models		
		Null	NA
		Stream depth	Stream depth
		Leaf depth	Leaf depth
		Buffer	Buffer
		Stream temperature	Stream temp.
		Sand	Sand
		Stream width	Stream width
		Course age	Age
		Retention	Leaf depth, stream depth
		Leaf area	Leaf depth, buffer
		Hydrology	Stream depth, stream width
		Global	All variables
Adults and juveniles			
	Abundance & Diversity Models	Null	NA
		Soil temperature	Soil temperature
		Stream depth	Stream depth
		Cover rocks	Cover rocks
		Leaf depth	Leaf depth
		Soil Moisture	Soil moisture
		Buffer	Buffer
		Stream	Stream depth, cover rocks
		Yin Yang	Leaf depth, stream depth
		Crawford	Leaf depth, soil moist, soil temp
		Global	All variables

Table 3. Top *a priori* regression models predicting the abundance and diversity of larvae and metamorph and juvenile and adult stream salamanders within 60 stream reaches located on golf courses in western North Carolina, USA.

Model	*K*[a]	*AIC_c*[b]	*ΔAICc*[c]	*ω_i*[d]
DIVERSITY				
Larvae & Metamorphs				
Retention	3	59.292	0.000	0.438
Leaf area	3	59.952	0.660	0.315
Stream depth	2	62.650	3.358	0.082
Leaf depth	2	63.362	4.070	0.057
Global	8	64.684	5.392	0.030
Adults & Juveniles				
Stream	3	39.218	0.000	0.792
Cover rocks	2	43.332	4.114	0.101
Global	7	43.336	4.118	0.101
Stream depth	2	50.584	11.366	0.003
YinYang	3	52.470	13.252	0.001

ABUNDANCE

Model	*-2 Log Likelihood*	*K*	*$QAIC_c$*[e]	*ΔQAICc*[f]	*ω_i*
Larvae and Metamorphs					
Leaf depth	210.572	3	113.047	0.000	0.464
Retention	210.530	4	115.325	2.277	0.149
Sediment	217.820	3	116.717	3.670	0.074
D.O.	218.526	3	117.075	4.027	0.062
Null	223.556	2	117.403	4.356	0.053
Adults and Juveniles					
Soil moisture	223.706	3	103.355	0.000	0.276
Leaf depth	226.79	3	104.691	1.336	0.142
Stream	222.362	4	105.071	1.716	0.117
Cover rocks	228.548	3	105.453	2.098	0.097
Stream depth	229.188	3	105.730	2.375	0.084

[a] *Number of parameters estimated in each model*

[b] *Akaike's Information Criterion adjusted for small sample size*

[c] *The difference between the AIC value for a given model and the AIC value of the best approximating model for each data set*

[d] *Akaike weights. Probability that the current model (i) is the best-approximating model*

[e] *Quasi Akaike's Information Criterion adjusted for small sample size*

[f] *The difference between the QAIC value for a given model and the QAIC value of the best approximating model for each data set*

Table 4. Model average parameter estimates (β), standard errors, and 95% confidence intervals based on model-averaged estimates for abundance and diversity analyses. Results in bold face type were significant (CI did not overlap zero).

	Covariate	df	β	SE	Lower	Upper
Leaf Bags						
	Abundance					
	Leaf depth	**1**	**.353**	**.137**	**.085**	**.621**
	Sediment	1	-.030	.022	-.072	.016
	CWD	1	-.041	.324	-.0595	.677
	Diversity					
	Stream depth	**1**	**-.555**	**.083**	**-.571**	**-.538**
	Leaf depth	**1**	**.074**	**.011**	**.053**	**.095**
	Buffer	**1**	**.007**	**.001**	**.005**	**.009**
VES						
	Abundance					
	Soil Moisture	**1**	**.081**	**.038**	**.007**	**.157**
	Leaf depth	1	.271	.191	-.103	.646
	Cover rocks	1	.423	.241	-.048	.895
	Diversity					
	Cover rock	**1**	**.124**	**.010**	**.104**	**.144**
	Stream depth	**1**	**-.380**	**.048**	**-.474**	**-.287**
	N/A					

Table 5. Analysis of 16 chemicals used in the treatment and management of golf courses in the Highlands-Cashiers region of North Carolina. An "X" indicates the chemical was not detected. Detection proportions are reported as averages in parts per million.

Chemical	Lower Level of Detection	Upstream (control) (N=6)	Detection frequency	Maximum Detection	Down stream (N=20)	Detection frequency	Maximum Detection
Tefluthrin	0.010	X	-	-	X	-	-
cis-Permethrin	0.010	X	-	-	X	-	-
trans-Permethrin	0.010	X	-	-	X	-	-
Cyfluthrin	0.010	X	-	-	X	-	-
Cyhalothrin	0.010	X	-	-	X	-	-
Cypermethrin	0.010	X	-	-	X	-	-
Fenvalerate	0.010	X	-	-	X	-	-
Deltramethrin	0.010	X	-	-	X	-	-
Chlorothalonil	0.010	X	-	-	X	-	-
Fipronil	0.010	X	-	-	X	-	-
Bifenthrin	0.010	X	-	-	X	-	-
4OH-Chlorothalonil	0.010	0.0027	1	0.054	0.0162	9	0.12
Azoxystrobin	0.020	X	-	-	X	-	-
Propiconazole	0.010	X	-	-	0.0135	8	0.135
Pyraclostrobin	0.020	X	-	-	X	-	-
Trifloxystrobin	0.020	X	-	-	X	-	-

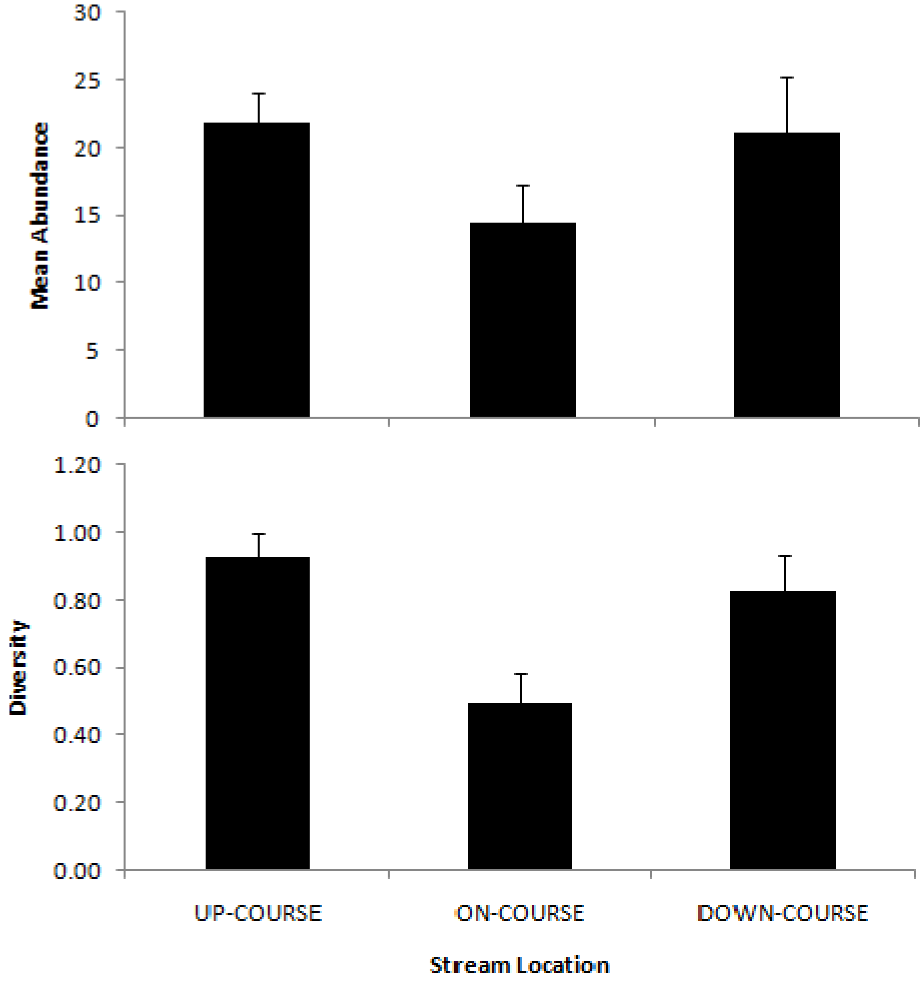

Fig. 1 Mean larval and metamorph salamander abundances and diversity from leaf bags located UP-course, ON-course, and DOWN-course of golf courses. Diversity indices (H') were derived from leaf bag captures (error bars ± 1 SE)

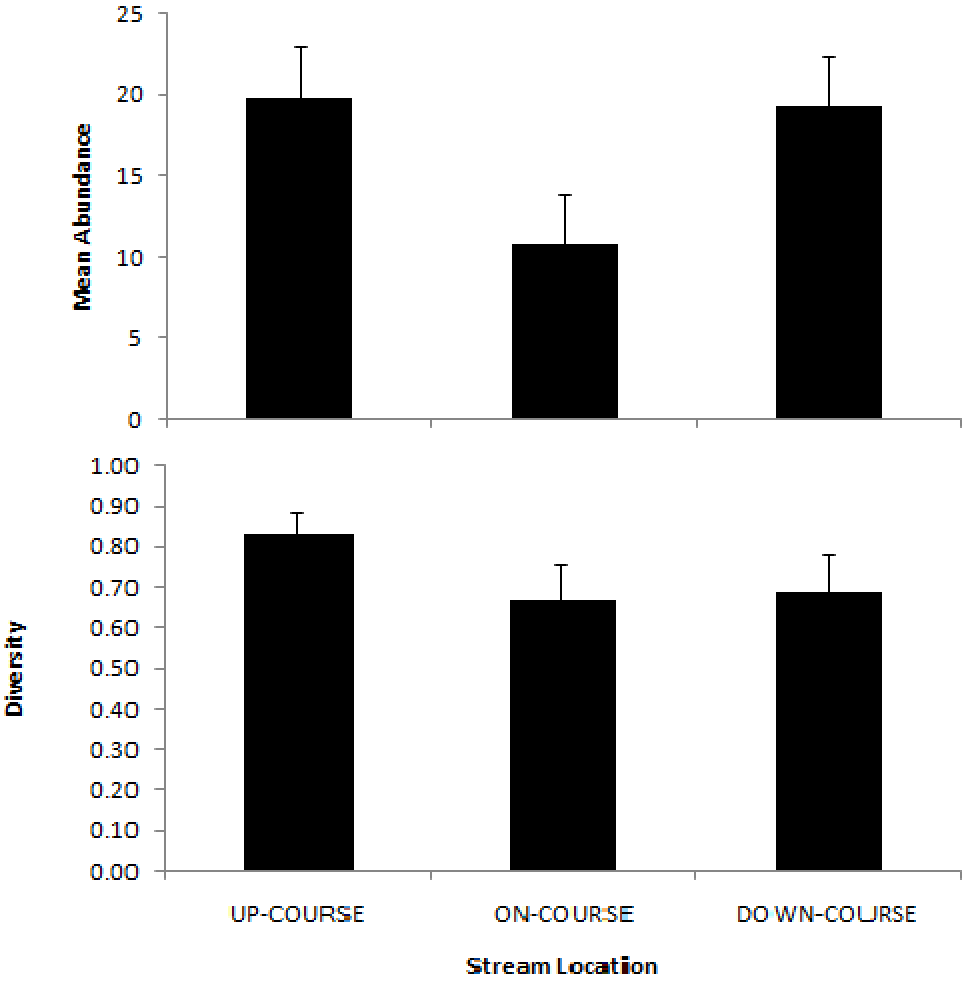

Fig. 2 Mean adult and juvenile salamander abundances (a) and diversity (b) from VES along streams located UP-course, ON-course, and DOWN-course of golf courses. Diversity indices (H’) were derived from VES total encounters (error bars ± 1 SE)

Chapter 3

SUMMARY AND MANAGEMENT IMPLICATIONS

Mark J. Mackey

Monitoring or stream salamanders: The utility of two survey techniques and the influence of stream substrate complexity (Chapter 1)

We conducted a study in which the primary objective was to determine how stream substrate complexity influences both capture rates and observed species richness of stream salamanders of two common sampling techniques, leaf litter bags and visual encounter surveys (VES), with the goal of developing monitoring recommendations to optimize capture rates and species detection ability. We found that catch per unit effort (CPUE) did not differ significantly between litter bag sampling and VES. Overall, we detected significantly more species in transects with complex substrate using both leaf litter bags and VES. This study demonstrated that leaf litter bag sampling and VES both have their strengths and weaknesses. Because different sampling techniques appear to target different ranges of species, we believe the use of more than one sampling technique may allow more accurate estimation of stream salamander abundances and species richness.

Examining the conservation value of golf courses: Management impacts on stream salamander abundance and diversity in the Southern Appalachian Mountains (Chapter 2)

The goal of our study was to assess the impact of current golf course management practices on stream salamanders by examining: 1) the effects of golf course management on stream salamander abundance and diversity, 2) the influence of in-stream and riparian habitat characteristics on salamander abundance and diversity, and 3) the presence and extent of chemical contaminant runoff from pesticide and fertilizer use.

Our results indicate that the focus of management efforts should be on the direct effects of golf course management on stream habitat rather than water quality or downstream effects. In general, golf course management and maintenance can lead to habitat homogenization and reduced structural complexity which has a negative effect on salamander abundance and diversity. Management efforts should be focused on preserving and restoring habitat complexity in and around headwater streams that are naturally typified as having high structural complexity which can support high biological diversity.

Management techniques developed for golf courses can also potentially be used in similar systems such as state parks, cemeteries, historical sites, and a number of other human land uses. As the golf industry becomes more open to land stewardship, sustainability, and ecological awareness, a valuable opportunity is provided for researchers to collaborate with this group of managers and provide constructive science-based guidelines for improvement.