BY MARK J. MACKEY, GRANT M. CONNETTE, WILLIAM E. PETERMAN, RAYMOND D. SEMLITSCH, DIVISION OF BIOLOGICAL SCIENCES, UNIVERSITY OF MISSOURI

Do golf courses reduce the ecological value of headwater streams for salamanders in the southern Appalachian Mountains?

Strategies to prepare Bermudagrass fairways for overseeding in the Desert Southwest have changed dramatically over the past five years.

ABSTRACT

Recent studies indicate golf courses may have a potential role in biodiversity conservation and management in human dominated landscapes. To serve this ecological role, effects of current golf course management practices must first be better understood. We sampled larval, juvenile, and adult stream salamanders in transects located upstream, through, and downstream of managed fairways of 10 golf courses in western North Carolina, USA. We measured in-stream and riparian habitat characteristics and tested for nitrate and pesticide chemicals to explain trends in salamander abundances and diversity. Stream transects located directly on fairways contained lower abundance of larval, metamorph, juvenile, and adult salamanders than either upstream or downstream transects. The species diversity of aquatic larval and metamorph salamanders on fairways was also reduced but only compared to the upstream transects, and terrestrial juvenile and adult diversity did not differ among the three transect locations. Our analysis found that leaf litter depth, CWD, soil moisture, and buffer width parameters found within several models were positive predictors of salamander abundance and diversity. Nitrate was not detected at any of the stream reaches and two of the 16 pesticide chemicals screened were only 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 streams running through fairways may be enhanced through simple management practices such as retaining woody debris, leaf litter, and restoring a riparian buffer.

INTRODUCTION

The ecological value of streams and rivers globally is influenced by increasing human land use (Allan, 2004). Currently, there are estimated to be more than 31,500 golf courses worldwide (Tanner & Gange, 2005). With over 18,300 golf courses in the U.S. alone (Baris, Cohen,

EDITOR'S NOTE

Due to the length of the original research report, the following is a modified version. To read the report in its entirety – including full content, references, and accompanying charts & graphs – see either the app version of this issue, or enter **bit.ly/1IYgeow** into your browser to access the pdf.

Real Science

Barnes, Lam, & Ma, 2010) encompassing over 2.7 million acres (Colding, Lundberg, Lundberg, & Andersson, 2009), golf has become an appreciable portion of land use in the United States. The ecological impacts of golf courses are not always straightforward, and popular opinion of the impacts of golf courses on the environment can be in direct opposition of scientific studies (Wheeler & Nauright, 2006). Further, results from the scientific literature can be seemingly as contradictory in their reporting (see below). To better understand the ecological impacts of golf courses, it is necessary to move beyond the deceptive dichotomy of "good" or "bad" (Sheil & Meijaard, 2010), and to measure impacts using ecologically meaningful responses for target organisms.

A major focus of discussion regarding known or suspected eco-logical impacts of golf courses has been water quality, typically focusing on chemical toxicology (Wheeler & Nauright, 2006). Golf courses depend on agrochemicals for pest control, turf management, and esthetic purposes. Although there have been many studies on agricultural chemicals in groundwater and surface water, it is usually not appropriate to extrapolate results from agricultural monitoring studies to golf course studies due to the significantly different management practices, plant canopy, surface mat, and root system of turf (Cohen, Svrjcek, Durborow, & Barnes, 1999; Kenna, 1995). A study in southeastern North Carolina reported generally greater nitrate levels in streams leaving golf courses compared to streams entering golf courses (Mallin & Wheeler, 2000), though concentrations varied considerably among courses. A study conducted on two golf courses under construction and five in operation in Canada found course construction and operation had a significant impact on alkalinity, nitrogen, and base cation concentrations of streams downstream of courses compared to forested reference streams (Winter & Dillon, 2005). A similar study found significant differences in certain benthic algal taxa in headwater streams downstream of golf courses compared to reference streams (Winter, Dillon, Paterson, Reid, & Somers, 2003). Differences were attributed to greater nutrient enrichment, higher pH, and higher disturbance from the golf courses.

Not all studies on the effects of golf courses find significant impacts on water chemistry. A study conducted on three golf courses in North Carolina examined the presence of chemicals in surface waters and found no chemical impact (Ryals, Genter, &Leidy, 1998). Another study in the Pacific Northwest monitored surface waters monthly following the application of fertilizers and pesticides and found no significant detection of chemicals (Hindahl, Miltner, Cook, & Stahnke, 2009). In fact, the most extensive meta-analysis to date of golf course water quality monitoring analyzed data from across 40 studies involving 80 courses over a 20-yearperiod and found relatively few pesticide detections or exceeded limits in surface water (Baris et al., 2010). The authors attribute this finding to the combination of two factors: (1) the fact that turf systems act as a living filter, and (2) the practice of applying minimal pesticides to the roughs, which typically surround the more intensively managed tees, greens, and fairways. As turf science has developed due to public scrutiny and pesticide registration evaluations by the U.S. Environmental Protection Agency under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA; Bariset al., 2010), it is possible that water chemistry and chemical runoff is no longer the foremost ecological concern at many golf courses.

The other primary impact of golf course development and maintenance is the physical alteration of the landscape. Habitat alteration and destruction is known to be one of the biggest threats to biodiversity (Wilcove, Rothstein, Dubow, Phillips, & Losos, 1998), and is therefore an obvious focus of ecological research. The clearing of natural vegetation, deforestation, the destruction of natural landscapes and habitat, and changes in local topography and hydrology are all possible land use effects that result from golf (Wheeler & Nauright, 2006; Winter et al., 2003). A study in southeast Queens-land, Australia found many golf courses to have negligible value as terrestrial habitat refuges which supported mostly urban-adapted species compared to reference eucalypt forests (Hodgkison, Hero, & Warnken, 2007). In stream ecosystems, reach-level channel morphology is influenced by valley slopes, bed and bank material, riparian vegetation, and the supply of upslope water, sediments, and wood (Montgomery & MacDonald, 2002). Human actions at the landscape scale can disrupt these factors that maintain stream processes and their associated biota and often result in habitat that is both degraded and less heterogeneous (Allan, 2004). Landscape level experiments have documented how such physical alterations to the terrestrial landscape can have downstream impacts on habitat and water quality of streams through alterations of hydrology (Likens & Bormann, 1974). Headwater streams in particular represent the maximal interface between aquatic-terrestrial systems (Lowe & Likens, 2005), and their sensitivity to land disturbance makes them both important and useful for studying land-use impacts.

> "Considering ecological processes are now more widely accounted for in golf course design and management, courses could increasingly become an asset in ecosystem management and biodiversity conservation and serve as models for ecological awareness and sustainability.

Despite the potential negative impacts golf course development and maintenance can have on landscapes, a number of studies have found golf courses to have a general positive conservation value on the species studied, including amphibians(Boone, Semlitsch, & Mosby, 2008; Colding, Lundberg, Lindberg,

& Andersson, 2009), butterflies (Porter, Pennington, Bulluck, &Blair, 2004) pond breeding macroinvertebrates (Colding, Lundberg,Lindberg, & Andersson, 2009), reptiles (Harden, Price, & Dorcas,2009; Mifsud & Mifsud, 2008), birds (Merola-Zwartjed & DeLong,2005; Rodewald, Rodewald, & Santiago, 2004), and mammals(Eisenberg, Noss, Waterman, & Main, 2011). A review of the scientific literature studying land-use effects of golf courses on biota found that the ecological value of golf courses increased as the anthropogenic impact on the surrounding land increased (Colding & Folke, 2009). Therefore, the ecological impact and conversely the conservation value of a golf course will depend upon the landscape in which the golf course exists. Additionally, studies of golf course impacts have often focused on single species or closely related taxa most likely as a result of logistical constraints of field work. Many of the species studied have dramatically different life histories and therefore respond differently to landscape alterations. Having a clear understanding of species life history in conservation efforts offers good opportunities to gain insight into the mechanisms behind species response to land-use change (Verheyen, Honnay, Motzkin, Hermy, & Foster, 2003).

> "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 ecologically-based guidelines for improvement of water quality and wildlife habitat.

Salamanders are especially prolific in headwater streams of eastern North America where they are the most abundant vertebrate organism (Peterman, Crawford, & Semlitsch, 2008; Nowakowski & Maerz, 2009). Because they are highly philopatric, long-lived, and occur in relatively stable populations, stream salamanders may be more appropriate and reliable indicators of biodiversity and habitat quality in stream ecosystems than many 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, Nislow, & Bolger, 2004; Welsh & Ollivier, 1998), and stream acidification (Kucken, Davis, Petranka, & Smith, 1994). Stream salamanders also have complex life cycles; reproduction and larval growth occurs in aquatic habitat followed by metamorphosis and sexual maturation interrestrial riparian habitat (Petranka, 1998). Thus, unlike some organisms, their persistence in headwater streams is explicitly dependent upon the quality of both aquatic and terrestrial systems.

The purpose of our study was to examine the influence of golf course management on the abundance and diversity of stream salamanders in the southern Appalachian Mountains. We focused on habitat changes that may have affected the abundance of both aquatic larvae and terrestrial juveniles and adults. Our primary hypothesis was that land-use effects would be greatest in stream samples that occurred directly on the golf course fairways because they would be directly impacted by habitat alteration during construction and routine maintenance of fairways compared to upstream or downstream areas that had no direct alteration or maintenance. We hypothesized that habitat alteration would either directly or indirectly affect aquatic larvae and terrestrial juveniles through loss of canopy cover, siltation, and a reduction in leaf litter, woody debris, and soil moisture based on similar studies in reference streams in the surrounding Nantahala National Forest (e.g., Crawford & Semlitsch, 2007, 2008; Peterman & Semlitsch, 2009). Secondarily, we tested whether chemical runoff in downstream samples was detectable at levels that might influence the abundance and diversity of salamanders on golf courses. Our objectives were to sample larvae, juvenile, and adult salamanders across a replicate set of 10 golf courses and test our hypotheses by comparing abundance and diversity between samples from streams located upstream, downstream, and through the fairway of each golf course. Further, we use an information theoretic approach to identify specific habitat features that are associated with either the abundance or diversity of stream salamanders.

CONCLUSIONS

Considering ecological processes are now more widely accounted for in golf course design and management (Jackson, Kelly, & Brown, 2011), courses could increasingly become an asset in ecosystem management and biodiversity conservation (Colding & Folke, 2009) and serve as models for ecological awareness and sustainability. With an estimated 27.1 million golfers in 2009 in the United States alone (NGF, 2010), integration of ecological principles to golf courses 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). From the application of our results, and building on previous studies, we suggest several procedures to improve golf course management: (1) maintain or restore riparian vegetation that includes a buffer at least 15 m from the stream edge, (2) maintain or restore a tree stocking density of ~50% within the riparian buffer to shade and provide a source of leaf litter, and (3)maintain or add small woody debris dams that retain leaf litter in streams to provide increased refuge, maintain soil moisture, and provide food sources for salamanders. Further, these management techniques suggested for golf courses can potentially be used in other systems with headwater streams such as parks, cemeteries, historical sites, and a number of other hwman land uses that affect the quality of stream habitat. 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 ecologically-based guidelines for improvement of water quality and wildlife habitat. **GCI**

LISTEN HERE LISTEN HERE LISTEN HERE LISTEN HERE LISTEN HERE

SRN Podcast

The Superintendent Radio Network's (SRN) Kyle Brown continues the conversation with Dr. Raymond D. Semlitsch, Division of Biological Sciences, University of Missouri, and one of the four authors of this research paper. Enter **bit.ly/1mClnRP** into your browser to access the podcast.

SUPERINTENDENT RADIO NETWORK