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EFFECTS OF SEDIMENTATION ON THE DIVERSITY OF SALAMANDERS IN A SOUTHERN APPALACHIAN HEADWATER STREAM

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Abstract: Salamanders constitute a large portion of the animal biomass in southern Appalachian stream habitats. They are particularly sensitive to environmental degradation and serve as excellent indicators of stream ecosystem health because many species require both aquatic and terrestrial habitats to complete their life cycle. Urbanization creates physical instability within stream habitats by negatively affecting the stability of bank soils and availability of suitable microhabitats. The relative abundance of streamside salamanders and the availability of protective cover was assessed at three study sites along Mill Creek in the town of Highlands, Macon County, North Carolina, and compared to an undisturbed Nantahala National Forest reference site. Area-constrained searches of rocks demonstrated a significant reduction in salamander diversity in Mill Creek as a result of severe sedimentation and loss of microhabitat.

Key Words: Desmognathus; microhabitat; salamanders; sedimentation; southern Appalachians; streams; urbanization.

INTRODUCTION

Mill Creek is a 2.25 km stream that flows through the center of the southern Appalachian mountain town of Highlands, Macon County, North Carolina. It forms the headwaters of the Cullasaja River which flows through the Nantahala National Forest and empties into the Little Tennessee River in Franklin, North Carolina. Numerous homes with manicured lawns, paved roads, runoff ditches and drainage culverts occur along Mill Creek, and considerable silt deposition and a paucity of natural canopy results from urbanization in many areas. Consequently, water quality in the Cullasaja River gradually improves downstream (LTWA 2003). A Little Tennessee Watershed Association study of water quality and habitat trends for macroinvertebrates and fishes classified Mill Creek as "poor" (LTWA 2003). The North Carolina Department of Environmental and Natural Resources Division of Water Quality similarly categorized Mill Creek, based on surveys of benthic macroinvertebrates, as impaired in its entirety and cited the causes as stormflow scour downstream from a combination of gradient force and the high proportion of impervious surfaces in town, lack of upstream colonization sources, various toxicants and in-stream tributary impoundments, and loss of microhabitat resulting from sedimentation (NCDWQ 2002).

Salamanders are important predators in riparian communities and constitute a large portion of the animal biomass in most southern Appalachian stream habitats (Hairston 1949; Petranka and Murray 2001). Streamside salamanders are useful indicators of ecosystem health (Welsh and Ollivier 1998; Bisson et al. 2002) because of their site fidelity, larval periods, and sensitivity to environmental disturbances (Feder 1983; Raphael et al. 2002). They are especially susceptible to the degradation of riparian areas because many species require both aquatic and terrestrial habitats to complete their life cycle (Semlitsch and Bodie 2003). Terrestrial buffer zones serve as important core habitats for foraging, overwintering, and breeding by many semi-aquatic salamander species (Petranka and Smith 2005; Crawford and Semlitsch 2007), help to maintain stream microclimates (Brosofske et al. 1997), and prevent soil erosion and runoff of pollutants (Semlitch and Bodie 2003).

Urbanization creates physical instability within stream habitats by negatively affecting the stability of bank soils and the availability of suitable microhabitats (Orser and Shure 1972; Riley et al. 2005). Salamander diversity in streams is strongly correlated with density of rocks, which are used as protective cover and as nesting sites (Davic and Orr 1987; Hom 1987). Increased substrate embeddedness caused by sedimentation can greatly reduce the abundance of salamander species (Welsh and Ollivier 1998; Lowe and Bolger 2002; Lowe et al. 2004), and may disrupt the trophic structure in many smaller-order stream ecosystems (Hairston 1949; Orser and Shure 1972; Petranka and Murray 2001). We therefore examined how sedimentation in Mill Creek has affected the availability of microhabitat and diversity of salamanders.

METHODS

Three Mill Creek sites were selected based upon locations that had been previously surveyed for benthic macroinvertebrates (NCDWQ 2002) and fishes (LTWA 2003). A 25 m transect was established within the stream at each location. Average riparian buffer width was obtained by measuring the distance from the streambank to the forest edge at 12.5 m intervals on either side of the transect.

Condition of the stream habitat was assessed using established guidelines that score ten different habitat parameters including availability of cover objects, variability of pools, channel flow, bank stability, and riparian vegetative zone width (Barbour and Stribling 1994). Streams receiving a score of ≥90% were categorized as "excellent," 75–89% as "good," 60–74% as "fair," and ≤59% as "poor" (Barbour and Stribling 1994).

Site #1 was located above the town center along Laurel Street (35°03′/83°11′), site #2 was located near the center of downtown Highlands just below the end of Mill Creek Lane (35°03′/83°12′), and site #3 was located furthest downstream in a residential area near Brookside Lane (35°04′/83°12′). A reference site was also established along a section of Skitty Creek outside of Highlands within the Nantahala National Forest at Cliffside Recreational Area (35°05′/83°13′) for comparative purposes (NCDWQ 2002).

Eleven bi-weekly surveys of aquatic salamanders were conducted at each site from September to November 2006 using daytime area-constrained searches of cover objects (Petranka and Smith 2005). All rocks >10 cm in diameter that were movable and not embedded in sediment were turned over, tallied, and then replaced. Rocks were considered to be embedded if they sat more than halfway into the sediment and lacked apparent interstitial spaces underneath. Each salamander observed was identified to species, except for larvae which were identified only to genus. Snout-vent length (SVL) was measured (cm) for each salamander, but visually estimated for those which eluded capture. A minimum of two days' recovery time elapsed between each survey in order to minimize disturbances.

Several environmental variables were also measured at each site during each survey. Water and sediment depths (cm) were measured at three randomly selected points along the stream transect. Dissolved oxygen (mg/L) and water temperature (°C) were measured with a YSI 85 meter, and pH with a Hanna Instruments submersible probe.

Because plot sizes varied by differences in stream width, observations of salamanders were converted to salamanders per m^2. Similarly, numbers of rocks were converted to rocks per m^2. Comparisons of salamander density and environmental variables at each Mill Creek study site with those at the Skitty Creek reference site were performed using Student's *t*-tests. Spearman's rank analysis was used to examine correlations of the means for each habitat variable with numbers of salamanders observed per survey.

RESULTS

The stream habitat at Laurel Street site was assessed as "poor," as this section of Mill Creek had an average terrestrial buffer width of only 2.85 m, and had very few exposed rocks and a deep sediment layer (Table 1). The Brookside Lane site was also categorized as "poor" and had an average buffer zone of 8.85 m. Although this site did possess more rocks (Table 1), most were covered with a fine layer of sediment at the bottom of deep pools created by artificial dams. The Mill Creek Lane site, however, was assessed as "good," and had an average buffer zone of 27.3 m. This section had many rocks and relatively little sediment (Table 1), and water flow was swift with a lot of riffles. The Skitty Creek reference site, which had a buffer zone greater than 50 m on either side of the stream, was assessed as "excellent" habitat with lots of rocks (Table 1), frequent riffles, and shallow pools.

The water at all three Mill Creek sites was significantly deeper and warmer than that of Skitty Creek (Table 1). However, dissolved oxygen values were similar at all sites (Table 1). Water was significantly more acidic at Laurel Street, but was similar to the reference site at Mill Creek Lane and at Brookside Lane (Table 1). Cover objects (rocks) were significantly denser and sediment significantly less deep at Skitty Creek than at any of the three Mill Creek sites (Table 1).

Numbers for the salamander species observed at each site are summarized in Table 2. Salamander density was significantly greater at the Skitty Creek reference site as compared to all three Mill Creek study sites, as was the total number of species (Table 1). Nearly five times more salamanders occurred at the reference site ($n = 284$) as compared to Laurel Street ($n = 58$; Table 2), which had deep sediment and few rocks (Table 1). Significantly smaller salamanders were found furthest downstream at Brookside Lane (Table 1), but many individuals at this site were larval (Table 2). Observations of salamanders were significantly positively correlated with rock density ($r_s = 0.706$, df = 42, $p < 0.001$), and had a significant negative relationship with sedimentation ($r_s = -0.376$, df = 42, $p < 0.01$) and water depth ($r_s = -0.474$, df = 42, $p = 0.001$). No significant correlation existed between salamanders and any other habitat variable (Table 3).

DISCUSSION

Smaller-order headwater streams such as Mill Creek are often the first aquatic habitats to be affected by development and pollution (Willson and Dorcas 2003).

Table 1. Results of t-tests (df = 10) between each Mill Creek study site and the Skitty Creek reference site.

Variable	Laurel Street		Mill Creek Lane		Brookside Lane		Skitty Creek
	$\overline{X}$	t	$\overline{X}$	T	$\overline{X}$	t	$\overline{X}$
Water Depth (cm)	18.7 ± 0.9	−6.05**	25.5 ± 1.0	−16.72 **	29.1 ± 1.5	−19.20**	12.7 ± 1.2
Water Temperature (°C)	14.0 ± 0.8	−5.93**	13.9 ± 0.7	−6.59**	13.2 ± 0.7	−6.01**	12.0 ± 0.6
Dissolved Oxygen (mg/L)	10.1 ± 0.2	1.59	10.5 ± 0.1	−0.33	10.7 ± 0.2	−1.62	10.5 ± 0.3
pH	6.4 ± 0.1	5.94**	6.9 ± 0.2	−0.49	6.9 ± 0.1	−0.71	6.9 ± 0.2
Rocks/m^2	2.3 ± 0.3	−20.27**	2.3 ± 0.2	−19.48**	3.4 ± 0.3	−10.83**	6.4 ± 0.3
Sediment depth (cm)	7.2 ± 0.1	−20.64**	3.1 ± 0.1	−2.23*	4.9 ± 0.1	−15.17**	2.7 ± 0.1
Salamanders/m^2	0.06 ± 0.01	7.78**	0.06 ± 0.01	6.43**	0.07 ± 0.01	6.29**	0.24 ± 0.03
# Salamander Species	1.6 ± 0.3	5.19**	2.36 ± 0.3	3.03*	2.1 ± 0.2	5.39**	3.4 ± 0.2
SVL (cm)	3.2 ± 0.6	0.21	4.0 ± 0.6	−1.21	1.4 ± 0.3	6.57**	3.3 ± 0.3

* $p \leq 0.01$, **$p \leq 0.001$.

Table 2. Observations of salamanders (n) at each site. Larval forms often eluded capture and were identified only to genus.

Species	Common Name	Laurel St.	Mill Creek Ln.	Brookside Ln.	Skitty Creek
Desmognathus monticola Dunn	Seal Salamander	22	31	28	71
D. ocoee Nicholls	Ocoee Salamander	2	22	8	89
D. quadramaculatus (Holbrook)	Black-bellied Salamander	10	35	39	84
Eurycea wilderae Dunn	Blue Ridge Two-lined Salamander	7	2	0	8
Gyrinophilus porphyriticus (Green)	Spring Salamander	0	0	0	1
Desmognathus spp.	Unidentified larvae	17	7	32	31
Totals		58	97	107	284

Heavy urbanization along streams results in increased runoff from paved surfaces and instability of surrounding soils (Welsh and Ollivier 1998; Lowe and Bolger 2002; Lowe et al. 2004). Large volumes of water can create physical disruptions of salamander populations through the alteration of stream microhabitats (Orser and Shure 1972). Many species reproduce in headwater stream areas and dispersal of larvae often occurs via drift (Bruce 1985, 1986). High stormflows can carry away organic debris used by larvae (Smith and Grossman 2003), and can remove upstream sources of recolonization (Orser and Shure 1972). Artificial dams such as those at Brookside Lane also alter the habitat by creating deep pools, which can lead to a reduction in salamander abundance from increased predation by trout and other fish (Lowe and Bolger 2002; Lowe et al. 2004).

Sedimentation is a pervasive threat to the ecological integrity of small stream ecosystems (Lowe et al. 2004).

Table 3. Spearman correlation coefficients (r_s) of habitat variables with number of salamanders (df = 42).

Habitat variable	r_s
Rock density	0.706**
Sediment depth	−0.376*
Dissolved oxygen	−0.071
pH	−0.089
Water temperature	0.207
Water depth	−0.474**

* $p \leq 0.01$, **$p \leq 0.001$.

Erosion in areas with inadequate riparian buffer strips, such as Laurel Street, results in physical scouring of the stream channel and a reduction in habitat complexity as important microhabitats such as rocks become increasingly embedded (NCDWQ 2002). In this study, developed sites with minimal riparian vegetation zones were heavily silted, with a reduction in salamander diversity resulting most likely from the paucity of suitable stream microhabitat. As interstitial spaces between rocks are filled with sediment, the amount of protective surface cover from predators such as fish and larger salamanders is reduced or eliminated (Lowe and Bolger 2002, Lowe et al. 2004). Lack of cover objects may also affect the ability of larvae to avoid high current velocities, and may decrease prey availability (Smith and Grossman 2003).

Rocks and streambank burrows also provide protection against desiccation and serve as nesting areas (Stewart and Bellis 1970; Hom 1987). Sediments that are deposited on salamander eggs or that restrict access to egg-laying sites on the undersides of rocks may impair reproduction (Lowe and Bolger 2002). As retreats are depleted, competition and predation between species may increase and shift community structure (Krzysik 1979; Southerland 1986; Roudebush and Taylor 1987). In contrast, the physical stability and heterogeneity of microhabitat offered in less disturbed, natural streams like Skitty Creek allows for larger and more stable populations of salamanders (Hairston 1949; Kleeberger 1985; Southerland 1986; Smith and Grossman 2003).

Our study demonstrates how anthropogenic disturbance in riparian areas can negatively affect the abundance and diversity of salamanders by reducing the amount and availability of cover objects. Sites with minimal riparian buffer zones were consequently the most silted and had the lowest diversity of salamander species. Although this was most likely as a result of insufficient microhabitat, other factors such as possible environmental toxins contained in sediments from runoff should also be considered (Kuken et al. 1994; Boone and James 1997; NCDWQ 2002). Wide riparian buffer zones are necessary to maintain healthy populations of salamanders not only because they prevent soil erosion and runoff, but because they also serve as core habitats for foraging and breeding (Petranka and Smith 2005; Crawford and Semlitsch 2007).

Salamanders constitute a large portion of the animal biomass in southern Appalachian stream habitats, and play an important role in trophic transfer and energy flow (Petranka and Murray 2001). They are particularly sensitive to environmental degradation because they spend the majority of their life cycles within streams and the immediate vicinity (Semlitsch and Bodie 2003). Although the preservation of wide strips of native vegetation along stream banks (Crawford and Semlitsch 2007) increases streambank stability and helps to mediate many of the effects of sedimentation on salamander diversity in southern Appalachian headwater streams, responses to anthropogenic disturbance depend on spatial context and scale, and that response may persist longer than the perturbation itself (Grover and Wilbur 2002). Therefore, long-term conservation efforts should also consider land use throughout the entire watershed, not just within narrow riparian zones (Willson and Dorcas 2002).

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