available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/biocon

Three decades of urbanization: Estimating the impact of land-cover change on stream salamander populations

Steven J. Price[a,*], *Michael E. Dorcas*[a], *Alisa L. Gallant*[b], *Robert W. Klaver*[b], *John D. Willson*[c]

[a]*Department of Biology, Davidson College, Davidson, NC 28035-7118, United States*
[b]*USGS Center for Earth Resources Observation and Science, Sioux Falls, SD 57198, United States*
[c]*Savannah River Ecology Laboratory, Drawer E, Aiken, SC 29802, United States*

A R T I C L E I N F O

Article history:
Received 7 November 2005
Received in revised form
17 May 2006
Accepted 13 July 2006
Available online 6 September 2006

Keywords:
Desmognathus fuscus
Eurycea cirrigera
Land cover change
North Carolina
Northern dusky salamander
Southern two-lined salamander
Urban sprawl

A B S T R A C T

Urbanization has become the dominant form of landscape disturbance in parts of the United States. Small streams in the Piedmont region of the eastern United States support high densities of salamanders and are often the first habitats to be affected by landscape-altering factors such as urbanization. We used US Geological Survey land cover data from 1972 to 2000 and a relation between stream salamanders and land cover, established from recent research, to estimate the impact of contemporary land-cover change on the abundance of stream salamanders near Davidson, North Carolina, a Piedmont locale that has experienced rapid urbanization during this time. Our analysis indicates that southern two-lined salamander (*Eurycea cirrigera*) populations have decreased from 32% to 44% while northern dusky salamanders (*Desmognathus fuscus*) have decreased from 21% to 30% over the last three decades. Our results suggest that the widespread conversion of forest to urban land in small catchments has likely resulted in a substantial decline of populations of stream salamanders and could have serious effects on stream ecosystems.

1. Introduction

Urbanization has become a dominant landscape-altering human activity in portions of the United States (Czech et al., 2000; McKinney, 2002). Urban development diminishes many native animal populations via habitat loss and alteration and through the introduction of novel and human-subsidized predators (McKinney, 2006). Unlike other human-induced landscape modifications, such as those associated with forestry practices, urbanization nearly always represents a permanent change, allowing little chance for habitats to recover (Marzluff and Ewing, 2001). Urbanization is currently associated with more endangered species in the United States than any other human activity (Czech et al., 2000; Ewing et al., 2005).

Stream ecosystems are particularly sensitive to urbanization (Paul and Meyer, 2001). Impervious surfaces increase surface-water runoff, which can alter stream hydrology, geomorphology, chemical composition, and the integrity of riparian zones (Paul and Meyer, 2001). Stream salamanders may be especially vulnerable to disturbance of catchments because of sensitivity to changes in stream microhabitat (Welsh and Olliver, 1998) and alteration of the surrounding terrestrial habitats (Lowe and Bolger, 2002). Studies by Orser and Shure (1972) and Willson and Dorcas (2003) have demonstrated strong negative correlations between the amount of

* *Corresponding author:* Tel.: +1 704 894 2868; fax: +1 704 894 2512.
E-mail addresses: sjprice@davidson.edu (S.J. Price), midorcas@davidson.edu (M.E. Dorcas), gallant@usgs.gov (A.L. Gallant), bklaver@usgs.gov (R.W. Klaver), willson@srel.edu (J.D. Willson).
0006-3207/$ - see front matter
doi:10.1016/j.biocon.2006.07.005

urban land in catchments and the number of salamanders captured in the catchment streams.

Studies of land-cover changes from 1972 to 2000 in the southeastern United States show a significant increase in the amount of urban land and a corresponding reduction in the amount of forested habitat (Griffith et al., 2003; Gallant et al., 2004). In the Piedmont Ecoregion, small streams can support high densities of salamanders (Spight, 1967; Orser and Shure, 1975), and land use change has likely resulted in their decline. In this study, we integrate land-cover data from the US Geological Survey's (USGS) Land Cover Trends study (Loveland et al., 2002) with models estimating salamander abundances (Willson and Dorcas, 2003) to assess the potential impact that land cover change in recent decades has had on stream salamander populations near Davidson, North Carolina.

2. Methods

Our study builds upon previous work by Willson and Dorcas (2003), who collected data on the relative abundance of larval and adult northern dusky salamanders (*Desmognathus fuscus*) and southern two-lined salamanders (*Eurycea cirrigera*) during 2001 in 10 first-order streams (average width 0.5–1.0 m, draining catchments <40.5 ha) located near Davidson, North Carolina. Davidson is situated in the northern part of the Charlotte Metropolitan area, one of the fastest-growing human populations in the United States (Ewing et al., 2005). The catchments of these 10 streams contained varying amounts of disturbance (defined as agricultural and residential/urban land uses), ranging from <20% to >50% of the catchment area. Both *D. fuscus* and *E. cirrigera* are common inhabitants of streams in the western Piedmont of North Carolina and are strongly associated with forested habitats (Petranka, 1998).

Willson and Dorcas (2003) used linear regression to examine the relationship between the amount of disturbed land in each stream's catchment and the number of *D. fuscus* and *E. cirrigera* captured in the streams. The data used to develop the model were normally distributed; thus, the model is valid under normal theory approximation. Strong inverse relations were identified, and models for both species were highly significant (*D. fuscus:* $y = -0.300x + 29.02$; $R^2 = 0.708$; $p = 0.001$ and *E. cirrigera:* $y = -0.429x + 30.37$; $R^2 = 0.480$; $p = 0.015$). We used these models for the current study to estimate the effects of land-cover change on the relative abundance of salamanders.

We acquired land-cover information from the USGS Land Cover Trends project (Loveland et al., 2002). This project mapped land cover for approximately 1973, 1980, 1986, 1992, and 2000 across a set of randomly selected, $20\ \text{km} \times 20\ \text{km}$ blocks contained within the Piedmont Ecoregion (US Environmental Protection Agency, 1999). We obtained the data for the block that encompasses the town of Davidson (Fig. 1; note, the image years for the Davidson block were 1972, 1981, 1985, 1992 and 2000). The USGS classification scheme includes 10 land cover categories that occur in the Piedmont Ecoregion (Gallant et al., 2004), seven of which occur in the Davidson block (Table 1). We aggregated the classification scheme to two land-cover categories, forested and disturbed, to fit the predictive models of salamander abundance from Willson and Dorcas (2003). We considered agricultural, residential, mined, and mechanically disturbed (i.e., area newly cleared of vegetation) lands to be disturbed habitat. We also considered permanent open water to be disturbed, as nearly all open water in this block represents reservoirs, which are not preferred habitat for *D. fuscus* or *E. cirrigera* (Petranka, 1998). A small portion (<2%) of the study block is mapped as wetland. Because the USGS did not distinguish forested from emergent wetlands, and because emergent wetlands are not preferred habitats for these two salamander species, we aggregated the wetland area with our non-forest, disturbed, class even though the area was not necessarily disturbed. There was little change in the wetland extent over time and, because wetland extent was so minimal in this block, the change did not have an appreciable effect on our analysis.

Catchment boundaries were provided by the USGS Elevation Derivatives for National Applications project (http://edna.usgs.gov). The catchments were delineated through a hierarchical, automated process applied to digital elevation

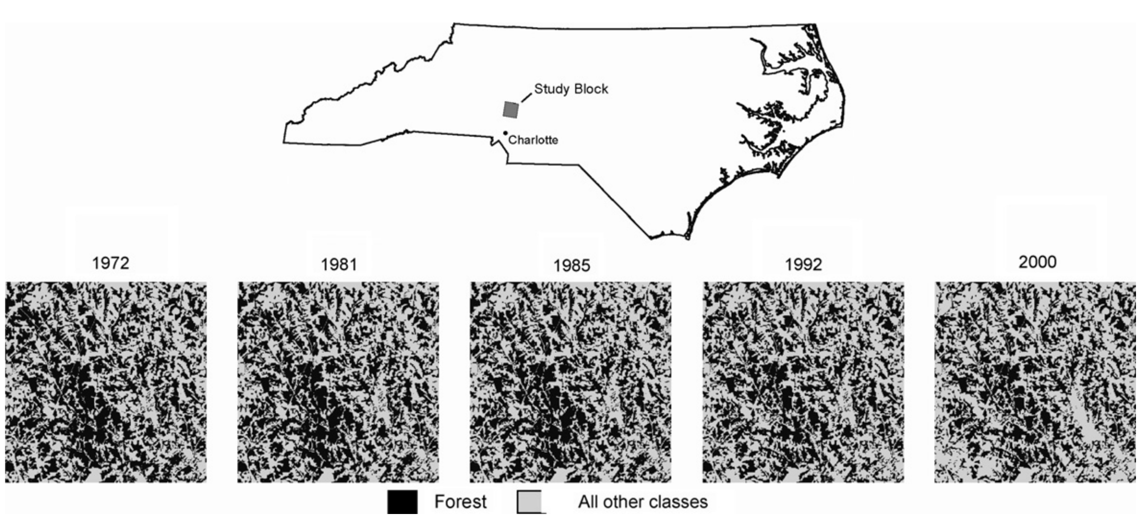

Fig. 1 – Land use changes near Davidson, North Carolina, from 1972 to 2000. Davidson sits in the rapidly-growing Charlotte Metropolitan area. Forested areas are shown in black; note the decrease in forest through time.

Table 1 – The percent land cover and total area changed for each cover class in the 400 km^2 study block from 1972 to 2000

Cover class	1972	1981	1985	1992	2000	% Block changed from 1972 to 2000
Forest	48.36	47.46	46.73	43.69	40.33	−8.10
Developed	15.69	16.40	16.73	18.18	23.22	+7.71
Mechanically disturbed	0.34	0.09	0.00	0.99	0.27	−0.07
Mining	0.05	0.05	0.05	0.33	0.31	+0.26
Agriculture	32.81	33.24	33.75	34.03	31.97	−0.91
Water	0.97	0.97	0.97	0.98	2.31	+1.33
Wetland	1.78	1.78	1.78	1.80	1.59	−0.21

Principle changes were the nearly 8% increase in developed (urban) land and the corresponding 8% decrease in forested land.

data (Franken, 2004). We extracted 1035 catchments that coincided with our study block and analyzed the hierarchic level corresponding with first-order streams. The majority of these catchments ranged in size from approximately 20 to 40 ha, matching the catchment sizes sampled by Willson and Dorcas (2003).

Using a geographic information system we overlaid the catchment boundaries on the land cover data for the study block and calculated the percent disturbed area for each catchment for each time period. We input the percent disturbed area into the regression models for both salamander species to estimate the number of salamanders in each catchment for each time period. In this analysis, we considered regeneration of forest to positively influence salamander abundance. Corn and Bury (1989) hypothesize that it may require up to 40 years for some western US stream salamander species (e.g., Olympic salamander, *Rhyacotriton olympicus*) to recolonize stream catchments after forest removal. Hence, in a second analysis, we calculated percent disturbed land and salamander abundance in each catchment using only those areas that remained forested since 1972.

We summed salamander abundance estimates (for both scenarios: forest/regeneration and always-forested) from each catchment to obtain the predicted total number of salamanders that would be captured for each time period, then used those predictions to calculate the percent change in salamander abundance between years. Additionally, we estimated the number of catchment extinctions for both species from 1972 to 2000 using both scenarios. Extinctions were calculated by summing the total number of catchments that resulted in an abundance of zero salamanders.

3. Results

Land-cover data for the study block showed a substantial increase in urban land and a corresponding decrease in forested land from 1972 to 2000 (Table 1). Other land use categories remained relatively stable during this time frame, although there was an increase in open water, due to the construction of a reservoir. When forest regeneration was considered as the equivalent of forest land, the average percent of disturbed land within individual catchments increased from 51% in 1972 to 61% in 2000 (a 10% increase). However, when we considered forest land to be only that which was forested continuously from 1972, then the proportion of disturbed land per catchment by 2000 was 65% (a 14% increase). Only slight increases in the average percent disturbed land occurred from 1972 to 1985, but the amount of disturbed land increased substantially from 1985 to 2000 (Fig. 2).

If forest regeneration is regarded as positively influencing salamander abundances, we predict the total number of *D. fuscus* to have been 14,187 in 1972 and 11,200 in 2000 (Fig. 3a), resulting in a 21% decline from 1972 to 2000 in the Davidson study block (Fig. 4a). We estimate the number of *E.*

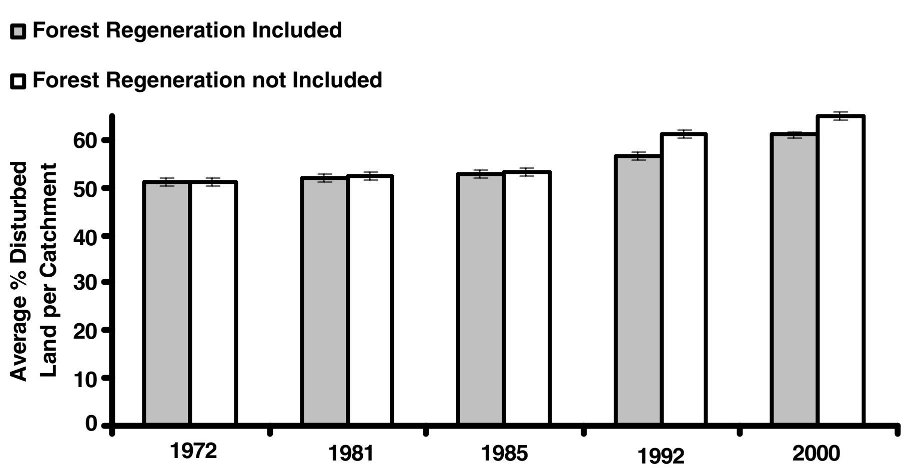

Fig. 2 – Average amount of disturbed land per catchment over time. Two scenarios are included. In the first, forested lands (including those in regeneration) are considered as undisturbed; in the second, only lands that have remained in forest since at least 1972 are considered as undisturbed. Error bars represent 1 standard error.

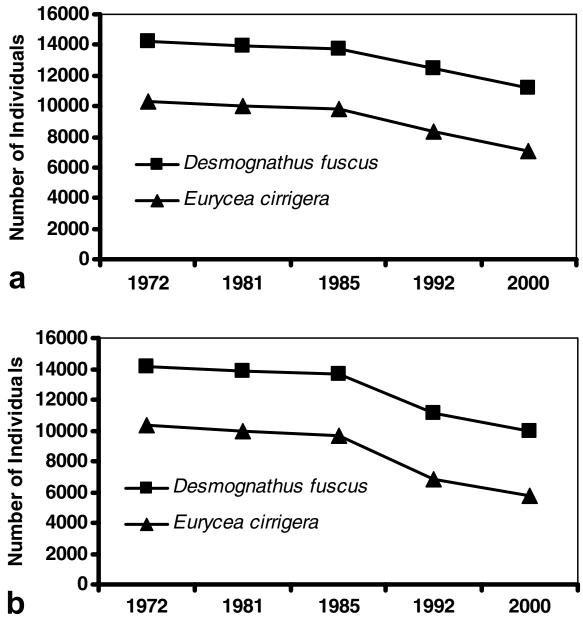

Fig. 3 – Estimated abundance in *Desmognathus fuscus* and *Eurycea cirrigera* populations near Davidson, North Carolina, from 1972 to 2000: (a) estimates were calculated with the total amount of forested area in each time period (i.e., forest regrowth increased salamander abundance estimates) and (b) estimates were calculated based only on areas that always remained forested (i.e., forest regrowth did not increase salamander abundance estimates).

cirrigera to have been 10,347 in 1972 and 7070 in 2000 (Fig. 3a), resulting in a population decline of 32% from 1972 to 2000 in the study block (Fig. 4a). We also predict that *D. fuscus* went extinct from 51 first-order streams (5.4% decrease) during that time, while *E. cirrigera* was eliminated from 139 first-order streams (18.2% decrease).

Predicted declines are greater if we do not consider forest regeneration to positively influence population estimates. Using this scenario, we estimate the abundance of *D. fuscus* to have been 9962 individuals and *E. cirrigera* to have been 5767 in 2000 (Fig. 3b). This suggests a 30% decline of *D. fuscus* populations and a 44% decline of *E. cirrigera* populations from 1972 to 2000 (Fig. 4b). We estimate that *D. fuscus* were locally extirpated from 71 catchments (7.5% decrease) and *E. cirrigera* were eliminated from 216 catchments (28.3% decrease).

4. Discussion

Our study used data on land-cover change to build upon a relation between stream salamander abundance and the percent of watershed covered by forest to identify threats to species and habitats in small catchments across a landscape. Small catchments, such as those modeled here, are numerous in many landscapes, but usually receive minimal protection and, thus, are improperly managed (Lowe and Likens, 2005). Consequently, the change in distribution and abundance of stream organisms, such as salamanders, is also poorly understood. By incorporating land-cover change data and catchment boundaries into salamander abundance models, we estimated a substantial decline in *D. fuscus* and *E. cirrigera* populations from 1972 to 2000 near Davidson, North Carolina. However, rates of declines were likely not constant across time, as most of the estimated declines occurred between 1985 and 2000, the period associated with the greatest increase in urbanization.

We considered percent forest cover to serve as a surrogate for identifying thresholds, where removal of forest cover is associated with increased frequency of high rainfall runoff events and other hydrological disturbances, which are likely detrimental to stream salamanders (Orser and Shure, 1972; Willson and Dorcas, 2003). From the standpoint of runoff, treating undisturbed and regenerating forest areas similarly in our models was reasonable, as the hydrology has not been permanently altered. What is not known, is whether salamanders vacate a catchment following forest removal, then return relatively quickly once the forest begins to regenerate or if considerable lag time exists between forest removal and salamander recolonization, as has been identified elsewhere (e.g., Corn and Bury, 1989). For that reason, we also modeled the scenario where regenerating forests were considered to be disturbed land. Connectivity among catchments may help to mitigate short-term effects of forest clearing on stream salamander populations and potentially facilitate dispersal from a minimally disturbed catchment to a catchment where forest regeneration occurred (Lowe and Bolger, 2002). However, the substantial amount of disturbed land within catchments of our study block suggests that salamanders from undisturbed, neighboring populations may have difficulty "rescuing" populations in previously disturbed streams.

Our models also assumed that all types of anthropogenically disturbed land use are equally detrimental to stream systems; yet, certain types of land use may be more damaging than others. For example, Moore and Palmer (2005) found that streams draining agricultural lands, where best management practices (e.g., intact riparian buffers, no-till farming) were employed had greater stream macroinvertebrate diversity than urbanized watersheds. Catchments containing mostly agricultural land may be less detrimental to stream salamanders than catchments dominated by urban land, especially if best management practices are utilized. In our study area, the conversion of forest to urban land was the dominant land-cover change from 1972 to 2000; therefore, our estimates of change in stream salamander abundance were not greatly influenced by the change in agricultural area.

Our estimates of stream salamander decline should be viewed only as estimates. The model we used (Willson and Dorcas, 2003) was based on recent field data. An assumption inherent in our approach is that the relation identified between the stream salamanders and percent forest cover has been consistent through time. Historic amphibian data are not available to validate the model back in time. Additionally, other factors, such as competition and predation among salamander species and other stream organisms (Southerland, 1986), microhabitat availability (Petranka, 1998), water quality (Gore, 1983), and land use history (Harding et al., 1998) may also have influenced the current abundances of salamanders near Davidson, North Carolina. Nonetheless, landscape-scale habitat alteration and destruction are among the primary causes for many amphibian declines throughout the world

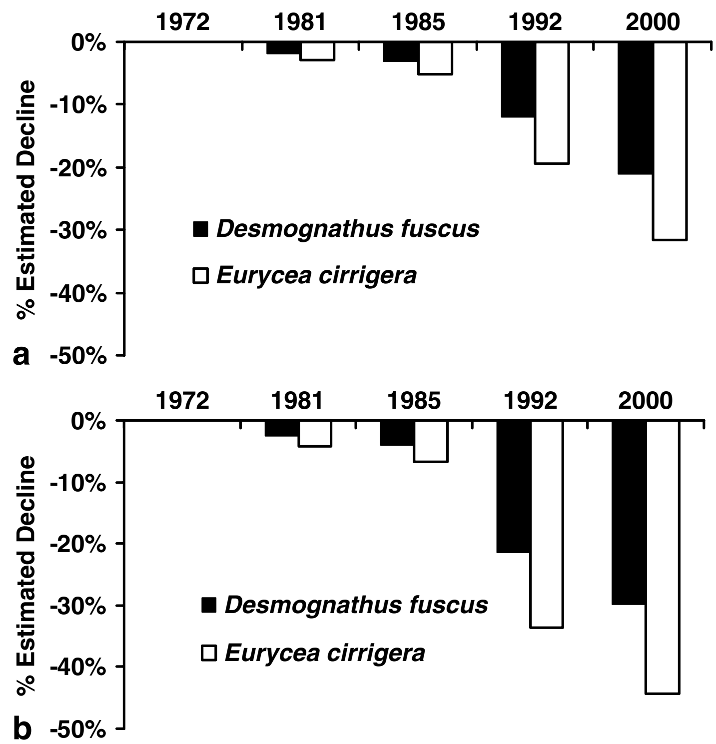

Fig. 4 – Estimated cumulative percent decrease in *Desmognathus fuscus* and *Eurycea cirrigera* populations near Davidson, North Carolina, from 1972 to 2000: (a) estimates were calculated with the total amount of forested area in each time period (i.e., forest regrowth increased salamander abundance estimates) and (b) estimates were calculated based only on areas that always remained forested (i.e., forest regrowth did not increase salamander abundance estimates).

(Dodd and Smith, 2003). Our findings suggest that the increasing rate of urbanization from 1972 to 2000 near Davidson, North Carolina may have resulted in a significant and rapid decline in stream salamander populations.

Rapid decreases in stream salamander abundance could have serious implications for stream ecosystems. Salamanders are often the dominant vertebrate in streams, and can reach extremely high population densities and biomass (Spight, 1967; Orser and Shure, 1975; Petranka and Murray, 2001). They are important predators of stream invertebrates, possibly functioning as "keystone species," as they promote invertebrate species and functional-group diversity by preventing dominant invertebrate species from monopolizing limited resources (Davic, 1983; Davic and Welsh, 2004). Similarly, stream salamanders may regulate the processing of detritus-litter by invertebrates (Burton and Likens, 1975a; Davic, 1983) and, thus, indirectly slow the release of nutrients and fine particulate matter to downstream areas. Stream salamanders also serve as prey for birds, mammals, reptiles and other organisms (Petranka, 1998), and are likely important nutrient vectors from aquatic to terrestrial environments (Burton and Likens, 1975b; Corn et al., 2003).

Rapid land-cover changes, particularly the urbanization of forested landscapes, are not unique to the Davidson block. From the early 1970s to 2000, urban land has increased from approximately 12% to 16% while forested land has decreased from 60% to 55% throughout the Piedmont (Griffith et al., 2003). Since the ranges of both *D. fuscus* and *E. cirrigera* encompass most of the Piedmont, we suspect these species and other amphibians could be declining throughout the region. To prevent or reverse population declines of stream salamanders, first-order streams require protection, and urban development needs to be mediated to minimize the effect on aquatic systems. Focusing future development into existing urban and suburban areas, building more compact neighborhoods, and progressive planning strategies may reduce some of the impacts of urbanization on stream systems. Ultimately, an approach that focuses on the broader landscape, such as protection and connectivity among catchments, may be most beneficial to minimize the impacts of urbanization. Such protection will not only benefit stream salamanders and first-order stream ecosystems, but will also have positive impacts on regional hydrology and the water quality of downstream aquatic systems.

Acknowledgements

We thank the many private landowners for use of their property to sample salamanders. Charles R. Peterson provided valuable advice and encouragement during the development of this project. Sandra Franken supplied the high-resolution USGS EDNA catchment boundaries used for our analysis. We thank Stephen C. Richter, Terry Sohl, Kristine Verdin and Craig Walters for providing comments on the manuscript. Manuscript preparation was aided by the Environmental Remediation Sciences Division of the Office of Biological and Environmental Research, US Department of Energy through Financial Assistance Award (DE-FC09-96SR18546) to the University of Georgia Research Foundation. Funding was provided by the Department of Biology at Davidson College, National Science Foundation grant (DEB – 0347326) to M.E.D., Duke Power, and the USGS Amphibian Research and Monitoring Initiative.

REFERENCES

Burton, T.M., Likens, G.E., 1975a. Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire. Ecology 56, 1068–1080.

Burton, T.M., Likens, G.E., 1975b. Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. Copeia 1975, 541–546.

Corn, P.S., Bury, R.B., 1989. Logging in Western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology and Management 29, 39–57.

Corn, P.S., Bury, R.B., Hyde, E.J., 2003. Conservation of North American stream amphibians. In: Semlitsch, R.D. (Ed.), Amphibian Conservation. Smithsonian Institution, pp. 24–36.

Czech, B., Krausman, P.R., Devers, P.K., 2000. Economic associations among causes of species endangerment in the United States. BioScience 50, 593–601.

Davic, R.D., 1983. An Investigation of Salamander Guild Predation in a North Carolina Stream: An Experimental Approach. Dissertation, Kent State University.

Davic, R.D., Welsh Jr., H.H., 2004. On the ecological roles of salamanders. Annual Review of Ecology, Evolution and Systematics 35, 405–434.

Dodd Jr., C.K., Smith, L.L., 2003. Habitat destruction and alteration: historical trends and future prospects for amphibians. In: Semlitsch, R.D. (Ed.), Amphibian Conservation. Smithsonian Institution, pp. 94–112.

Ewing, R., Kostyack, J., Chen, D., Stein, B., Ernst, M., 2005. Endangered by Sprawl: How Runaway Development Threatens America's Wildlife. National Wildlife Federation, Smart Growth America, and NatureServe.

Franken, S.K., 2004. USGS EROS Data Center Produces Seamless Hydrologic Derivatives with GIS. ArcNews, Fall 2004. Available from: <http://www.esri.com/news/arcnews/fall04articles/usgs-eros.html> (accessed October 2005).

Gallant, A.L., Loveland, T.R., Sohl, T.L., Napton, D.E., 2004. Using an ecoregion framework to analyze land-cover and land-use dynamics. Environmental Management 34 (S1), S89–S110.

Gore, J.A., 1983. The distribution of desmognathine larvae (Amphibia: Plethodontidae) in coal surface impacted streams of the Cumberland Plateau, USA. Journal of Freshwater Ecology 2, 13–23.

Griffith, J.A., Stehman, S.V., Loveland, T.R., 2003. Landscape trends in Mid-Atlantic and Southeastern United States ecoregions. Environmental Management 32, 572–588.

Harding, J.S., Benefield, E.F., Bolstad, P.V., Helfman, G.S., Jones, E.B.D., 1998. Stream biodiversity: the ghost of land use past. Proceedings of the National Academy of Sciences of the United States of America 95, 14843–14847.

Loveland, T.R., Sohl, T.L., Stehman, S.V., Gallant, A.L., Sayler, K.L., Napton, D.E., 2002. A strategy for estimating the rates of recent United States land-cover changes. Photogrammetric Engineering and Remote Sensing 68, 1091–1099.

Lowe, W.H., Bolger, D.T., 2002. Local and landscape-scale predictors of salamander abundance in New Hampshire headwater streams. Conservation Biology 16, 183–193.

Lowe, W.H., Likens, G.E., 2005. Moving headwater streams to the head of the class. BioScience 55, 196–197.

Marzluff, J.M., Ewing, K., 2001. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Restoration Ecology 9, 280–292.

McKinney, M.L., 2002. Urbanization, biodiversity and conservation. BioScience 52, 883–890.

McKinney, M.L., 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127, 247–260.

Moore, A.A., Palmer, M.A., 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. Ecological Applications 15, 1169–1177.

Orser, P.N., Shure, D.J., 1972. Effects of urbanization on the salamander, *Desmognathus fuscus fuscus*. Ecology 53, 1148–1154.

Orser, P.N., Shure, D.J., 1975. Population cycles and activity patterns of the dusky salamander, *Desmognathus fuscus fuscus*. American Midland Naturalist 93, 403–410.

Paul, M.J., Meyer, J.L., 2001. Streams in the urban landscape. Annual Review in Ecology and Systematics 32, 333–365.

Petranka, J.W., Murray, S.S., 2001. Effectiveness of removal sampling for determining salamander density and biomass: a case study in an Appalachian streamside community. Journal of Herpetology 35, 36–44.

Petranka, J.W., 1998. Salamanders of the United States and Canada. Smithsonian Institution.

Southerland, M.T., 1986. Behavioral interactions among four species of the salamander genus *Desmognathus*. Ecology 67, 175–181.

Spight, T.M., 1967. Population structure and biomass production by a stream salamander. American Midland Naturalist 78, 437–447.

US Environmental Protection Agency, 1999. Level III Ecoregions of the Continental United States. US Environmental Protection Agency – National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. Digital map.

Welsh Jr., H.H., Olliver, M.L., 1998. Stream amphibians as indicators of ecosystem stress: a case study from California's Redwoods. Ecological Applications 8, 1118–1132.

Willson, J.D., Dorcas, M.E., 2003. Effects of habitat disturbance on stream salamanders: implications for buffer zones and watershed management. Conservation Biology 17, 763–771.