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Urbanization in the Southeastern United States: Socioeconomic forces and ecological responses along an urban-rural gradient

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Abstract Urbanization in the southeastern U.S. has progressed rapidly due to economic development and population growth. This is particularly the case in the Piedmont physiographic region of Georgia where an interdisciplinary group of researchers conducted a series of studies, collectively known as the West Georgia Project, to evaluate the causes and consequences of urbanization associated with a mid-size city (<200,000 pop). Although the results of this project have been presented as individual facets, in this manuscript, we will provide a comprehensive picture of the drivers and effects of urbanization across that landscape. First, socio-economic drivers of land use change in Georgia were identified. The feedback of urbanization influences on cultural responses, namely environmental knowledge, was studied in urban vs. rural watersheds. Additionally, an urban-rural gradient of selected watersheds was used to examine the effects of urban development on terrestrial and aquatic ecosystem structure and function. We hypothesized that negative feedbacks would occur as a result of environmental impacts that could alter the rate of development or its spatial distribution. These studies suggested that urbanization has greatly altered many environmental indices. However, environmental awareness seemed to decline as populations became more urbanized and, consequently, there was little indication that the previously mentioned negative feedbacks occurred. With continued conversion of forests to urban land expected through the foreseeable future, greater emphasis on outreach must occur in order to enhance environmental knowledge of rural and urban residents alike and to make urbanizing populations aware of any degradation of environmental quality.

Keywords West Georgia · Urbanization · Land use · Ecosystem function · Ecosystem structure

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Introduction

With more than half of the global population residing in cities, an understanding of urban systems has become critical. The field of urban studies has grown in response to expanding urban areas and includes socio-economic and biophysical components (Grimm et al. 2000; Alberti et al. 2003; Alberti 2008). Every day, new urban research from many disciplines is shared through international conferences (Urban Studies Conferences 2010), publications (Urban Studies Journal, Journal of Urban Affairs, International Journal of Urban and Regional Research, Urban Ecosystems, etc.), and city meetings and other outreach events at the local scale. A linked ecological and socioeconomic framework is necessary to evaluate problems of this level of complexity (Alberti et al. 2003; Lockaby et al. 2005).

Studies of ecological processes in urban areas have been advanced by research from the Long-term Ecological Research (LTER) sites in the U.S. in Baltimore, MD (Grove and Burch 1997; Cadenasso et al. 2006) and Phoenix, AZ (Grimm and Redman 2004), and internationally in cities such as Helsinki, Finland (Yli-Pelkonen and Niemelä 2006). Other notable contributions to urban studies within the U.S have also been made in New York City, NY and Seattle, WA (McDonnell and Pickett 1990; Cadenasso et al. 2006; Hutyra et al. 2010). Recently, the NSF initiative to fund Urban Long-Term Research Areas (ULTRA) has created new sites to enhance the understanding of human-environment interactions in urban areas. The westGA study is at a smaller scale (population of Columbus, GA is <200,000) than these other cities but adds critical knowledge to coupled natural-human systems.

Urban development at the expense of forests is a prominent pattern of land use change globally and in the southeast U.S. and is expected to continue in the coming years. Specifically, Wear (2002) predicted that the Southern Piedmont will be among the areas of greatest urban development in the Southeast. Conversion of land to urban uses in the Piedmont will be perpetuated by the increasing population in this region. Overall, the South will have the greatest absolute increase in population of any region in the U.S. (an increase of 43 million people) from 2000–2030, although the predicted growth rate for the West is slightly higher (45.8% vs. 42.9% for the southern and western U.S., respectively) for the same period (U.S. Census Bureau 2005). Results from a case study in west Georgia are presented here to illustrate the effects and processes associated with urban development in the Southeast. Similar patterns of increasing population and urbanization are occurring throughout the U.S., and globally, and thus it is hoped that the results from this study can be applied elsewhere.

Project description

The west Georgia (WestGA) project, established in 2000 by the Auburn University Center for Forest Sustainability, examined the influence of land use change, particularly urban development, on ecosystem structure and function (Lockaby et al. 2005). In addition to various ecological responses, the patterns and socioeconomic drivers of land use change were also explored and incorporated through a series of interdisciplinary investigations (Fig. 1). As the conceptual model illustrates, each element influences the next and together they form a comprehensive, interdisciplinary examination of the causes and effects of urban development (Fig. 1). To exemplify these components, the collection of studies of the WestGA project is listed in Table 1. Although each of these studies has individual merit, it is the integration of studies fostered by the framework of the WestGA project that greatly advances the understanding of urban systems. We hypothesized that environmental impacts from urbanization would serve as negative feedbacks as residents began

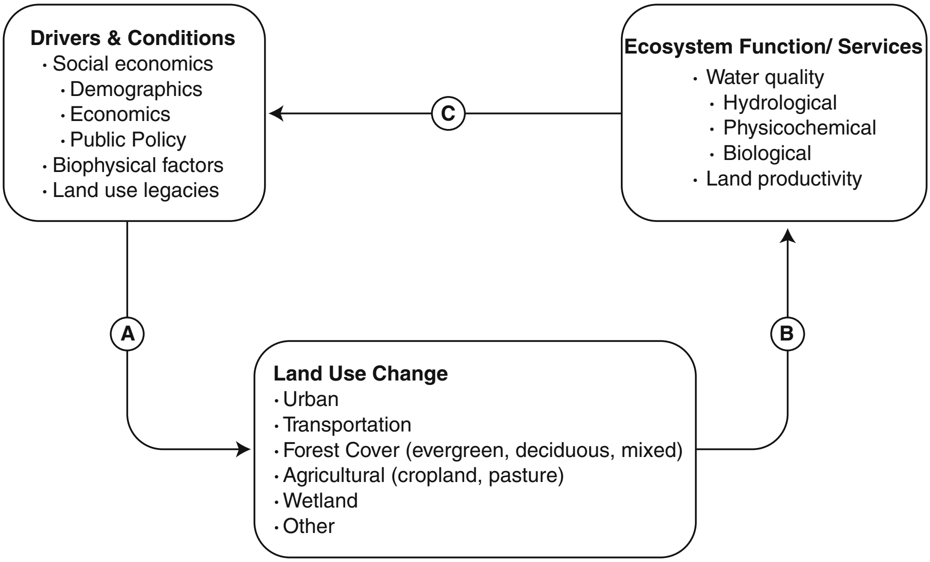


Fig. 1 Conceptual model for the westGA project; The 'A' arrow represents the function of the land use model, the 'B' arrow represents the ecosystem model, and the 'C' arrow represents the feedback mechanisms; Modified from Lockaby et al. (2005)

Table 1 Collection of WestGA studies

Group	Topic	Study
Drivers and conditions	Socioeconomics, population growth	Bhattarai et al. 2004
	Timberland	Nagubadi and Zhang 2005
Feedback	Environmental knowledge	McDaniel and Alley 2005
Ecosystem structure	Vegetation structure, non-natives	Burton et al. 2005
	Plant diversity	Burton and Samuelson 2008
	Plant diversity and non-natives	Loewenstein and Loewenstein 2005
	Plant traits and richness	Burton et al. 2009
	Coyotes	Billodeaux 2007
	Birds	Stratford and Robinson 2005
	Amphibians and reptiles	Barrett and Guyer 2008
	Fish populations	Helms et al. 2005
Ecosystem function	Stream hydrology	Schoonover et al. 2006
	Stream hydrology, sediment, nutrients, and bacteria	Crim 2007
	Stream sediment	Schoonover et al. 2007
	Stream sediment and nutrients	Schoonover et al. 2005
	Stream nutrients and bacteria	Schoonover and Lockaby 2006
	Ecosystem carbon storage	Zhang et al. 2008
	Invasive plants, carbon storage	Brantley 2008
	Invasive plants, nutrient cycling	Mitchell 2009
	Soil, tree, and lichen metals, N, and S	Styers and Chappelka 2009

to avoid particular locations and, consequently, the rate and spatial distribution of development might be altered.

The studies occurred along an urban-rural gradient from the city of Columbus, GA through areas of decreasing urban land extending to the northeast approximately 100 km. It is along this gradient that future urban development is expected to occur because Columbus is bounded on the southeast by Ft. Benning Military Reservation and the west by the Chattahoochee River. The counties of Muscogee, Harris, Meriwether, and Troup are included in this gradient (Fig. 2). Watersheds with varying proportions of forest, urban, and agricultural land were selected to study the causes of and responses to land use/cover change. A full description of the land use classification in west Georgia is provided in Lockaby et al. (2005).

West Georgia landscape

Like much of the Southeast, the Piedmont had a period of extensive agricultural use, primarily cotton, which peaked in the 19th century and left behind highly eroded and degraded soils. The timber industry became more prevalent following the decline of row-crop agriculture. Today the forest products industry is still important to the region, reflected in the fact that the Southeast produces more timber than any other region in the U.S. (Wear 2002; Ziewitz and Wiaz 2004). However, more recently forested land has been converted to urban uses to accommodate the growing population. The Southern Piedmont is expected to have the greatest forest losses in the South in coming years (Wear 2006). It is this most recent pattern of land use change that was the focus of the WestGA project.

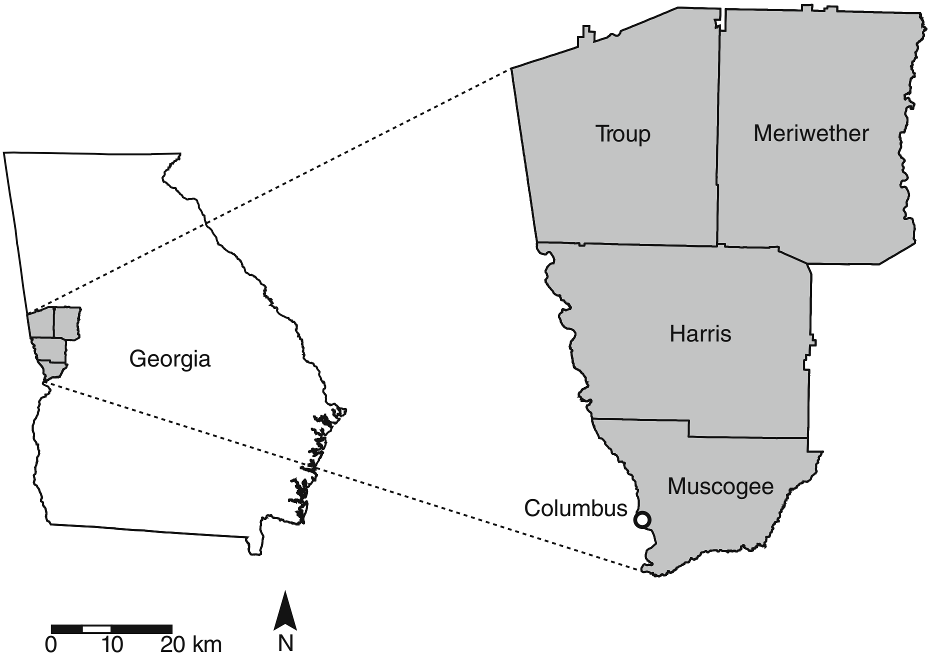


Fig. 2 Counties included in various westGA studies: Muscogee, Harris, Meriwether, and Troup

Drivers of land use change

Bhattarai et al. (2004) explained some of the recent trends in land conversions in west Georgia based on socioeconomic drivers such as increased population growth and disposable income. Per capita income increased 23% from 1992–2000 and had a significant negative influence on the proportion of agricultural land (Bhattarai et al. 2004). An increasing demand for land with development potential led to increased land prices in the urban core. As an example, the average price of an acre of farmland in Georgia Agricultural District 4 (location of the WestGA study area) rose from $1,095 to $4,601 between 1991 and 2001, corresponding to the second highest level in Georgia. When adjusted for inflation, this represents a 348% increase (Bergstrom et al. 2002). The share of developed land was positively related to a higher market concentration and road accessibility, but there were also interactions between urban and rural areas (Bhattarai et al. 2004). For example, there was a decrease in the number of people working near their home and an increase in average travel time to work. Land in commercial, industrial, and transportation uses in west Georgia increased by 323% from 1992–1998 (Bhattarai et al. 2004). Similarly, in Baltimore, Grove (1996) found a correlation between vegetation cover in urban areas and education and income.

Timberland in the state of Georgia decreased by 4% from 1972–2000 (Nagubadi and Zhang 2005). Per capita income was negatively related to timberland use and positively related to agricultural land use. The latter finding contradicts the results in Bhattarai et al. (2004) and may be due to the fact that Nagubadi and Zhang (2005) studied the entire state of Georgia as opposed to select counties in west Georgia. The share of timberland use was positively related to the weighted sawtimber price and negatively related to agricultural returns (Nagubadi and Zhang 2005). The authors explained that higher quality land is used for agriculture and lower quality land is used for forestry. Together, higher income and a higher proportion of good quality land can shift land uses to others besides forestry.

Nagubadi and Zhang (2005) suggested that timberland influences vary with ownership and forest type. For example, timberland owned by the public and forest industry increased 11% and 13% respectively, while non-industrial private forests decreased 9% in Georgia from 1972–2000. Higher forestry returns contributed to increases in industrial timberland but not non-industrial private forests (NIPF). Population density was positively related to the NIPF timberland share and negatively related to the industrial timberland share. In terms of forest type, there was an increase in hardwood forests (~12%) and a decrease in softwood (~13%) and mixed forests (~13%) in Georgia from 1972–2000 due to increased hardwood returns. However, increased softwood returns and tree planting assistance programs somewhat alleviated the softwood declines.

Feedback mechanisms

Cultural responses: Environmental knowledge

One of the driving factors behind the approach was our hypothesis that, if residents were aware of environmental degradation linked to development, this information might influence their choices regarding where to live. In other words, if water quality had been impacted in a given location, that location might no longer be as attractive for residential housing. However, although negative impacts of urbanization on water resources are well documented globally, implementation of protective measures is often problematic and ineffective due to failure of individuals and groups to accurately comprehend causes of water impairment (Bacic et al. 2006).

Environmental awareness is influenced by the interactions of humans with the natural landscape and influences their support of various environmental and ecological initiatives. McDaniel and Alley (2005) surveyed the environmental knowledge of respondents along the same urban-rural gradient in west Georgia. There was a high proportion (>80%) of respondents across the study area who understood that the presence of forests helps maintain water quality and that urbanization often leads to soil erosion. Environmental knowledge was influenced by geographic residence and participation in outdoor recreation, while education and income were of less importance. The mean environmental knowledge score of rural participants was higher than those living in developing and urban watersheds (McDaniel and Alley 2005). The highest scores among land uses were in managed pine watersheds and may be explained by the involvement of these residents in land management. For example, timber owners had higher scores than non-timber owners and landowners with streamside management zones, or SMZs, had higher scores than landowners without SMZs (McDaniel and Alley 2005). Those who identified themselves as active bird watchers were among the group with the highest scores among recreational activities (McDaniel and Alley 2005). It follows from this study that the disconnect of urban residents from nature may contribute to the lower environmental knowledge scores of this group.

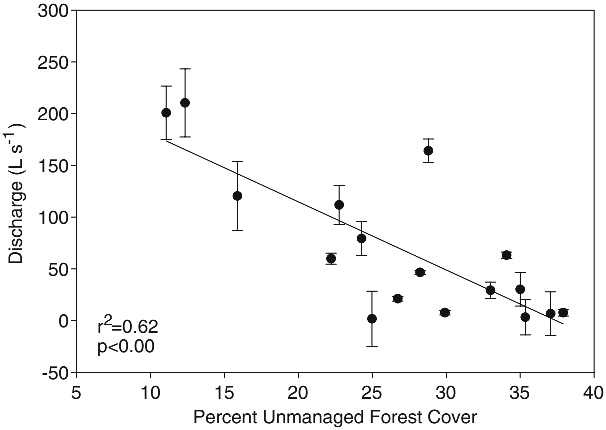
In order for negative feedbacks to function, there must be a mean for communicating environmental information to people. If this communication is ineffective, people cannot be expected to show responses in their decision making (Bacic et al. 2006). In the WestGa study area, the existence of strong mechanisms for transfer of environmental knowledge specifically related to urban impacts was not apparent. The lack of outreach opportunities regarding urban impacts suggests that the low environmental knowledge base of urban residents is likely to remain unchanged in the near future.

Ecosystem function

Hydrology

The influence of urbanization on stream hydrology has been characterized in other studies (de la Crétaz and Barten 2007) and is largely associated with the clearing of vegetation and introduction of impervious surfaces (IS). Vegetation removal decreases evapotranspiration and thus increases in water yield often accompany deforestation while decreases in water yield follow reforestation (Hibbert 1967; Bosch and Hewlett 1982). Increased impervious cover reduces infiltration and increases runoff. For example, Kaye et al. (2006) reported that with 10–20% IS in Baltimore, surface runoff doubled. Consequently, common observations in urban streams include increased peak flows and reduced base flows (Rose and Peters 2001; Calhoun et al. 2003; de la Crétaz and Barten 2007; Olivera and Defee 2007). Schoonover et al. (2006) and Crim (2007) supported these general findings in their studies in west Georgia. High flow pulses and elevated peak discharges were more frequent in urban watersheds and baseflow inputs were lower in urban streams compared to other land uses. Pastoral and forested watersheds showed less flashy hydrographs with lower mean and maximum discharges than urban watersheds. In west Georgia streams, discharge was negatively correlated with the proportion of uneven aged forest (Fig. 3) (Schoonover et al. 2006).

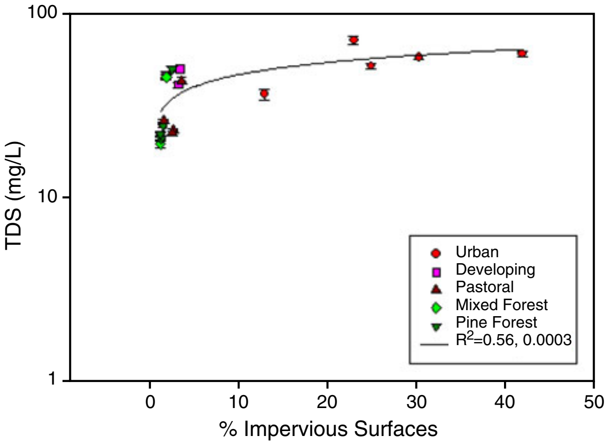
Fig. 3 Relationship between uneven aged forest cover and discharge; With permission from Schoonover et al. (2006)



Sediment and channel morphology

Land use change can increase erosion and alter stream sediment loads. Sediment increases in urban streams generally occur in two phases: 1) during clearing and construction fine sediments are imported from terrestrial sources and 2) with increased impervious surface coverage, peak flows increase and amplify within-channel erosion (Schoonover et al. 2007). In west Georgia, Schoonover et al. (2007) found that in stormflow, sediment in urban streams increased quickly. Total dissolved solids (TDS) concentrations and yields were 2× greater in urban streams than other land uses in both baseflow and stormflow, but total suspended solids (TSS) concentrations did not display differences among land uses (Schoonover et al. 2005, 2007). Further, TDS concentrations exhibited a curvilinear response as the % IS increased (Fig. 4) and thus were highest in urban watersheds (Crim 2007). Similar to these results, less-forested watersheds had higher TSS and TDS concentrations in the southern Appalachians (Price and Leigh 2006). In terms of sediment loads, Crim (2007) found that developing watersheds had the highest median TDS and TSS loads of all land uses, indicating the rapid rate at which water quality impacts were observed after the initial land conversion. For example, median TDS yields were 558.97,

Fig. 4 Concentrations of TDS (mg/L) with increasing IS cover; With permission from Crim (2007)



214.61, and 113.81 g/d/ha for developing, urban, and mixed forest watersheds, respectively (Crim 2007). Urban, developing, and pastoral streams all experienced scouring during the study period, while forested streams were aggrading or were relatively stable (Schoonover et al. 2007). Pastoral streams had the most unstable channels and may reflect historical as well as current land use practices (Schoonover et al. 2007).

Stream nutrients

Elevated nutrient concentrations are commonly observed in urban streams, even at low levels of development. With >5% IS, Cl^-, NO_3^-, SO_4^{2-}, and K^+ concentrations and loads were significantly higher in both baseflow and stormflow (Table 2) (Schoonover et al. 2005; Schoonover and Lockaby 2006). Clinton and Vose (2006) found similar patterns for Cl^-, NO_3^-, SO_4^{2-}, and K^+ in southern Appalachian streams. Nitrate was also high in pastoral streams, but the source of nitrate in pastoral streams is groundwater, while in urban areas it stems from runoff (Schoonover and Lockaby 2006). Ammonium was higher in urban watersheds only during stormflow, while Na^+ was higher in urban streams only in baseflow (Schoonover and Lockaby 2006). Higher ammonium in urban streams may be due to leaky sewers and septic systems and fertilizer runoff. The % pine and % mixed forest were negatively correlated with stream nutrient concentrations and variation (Schoonover et al. 2005; Crim 2007). Schoonover and Lockaby (2006) created regression models to predict changes in stream nutrients based on changes in land use. These models will be particularly helpful to anticipate stream changes as development occurs along the urban-rural gradient in west Georgia and also to compare to other regions. Interestingly, observable changes of stream nutrients occurred here at low levels of urban development (<5% IS) (Crim 2007), indicating lower thresholds than the 10–20% IS that is often quoted in the literature (Arnold and Gibbons 1996; Bledsoe and Watson 2001). In Baltimore, nitrogen loading was less in forested streams than either suburban or urban streams (Pickett and Cadenasso 2006). In that study, the authors attributed the highest nitrogen loading in suburban streams to fertilizer runoff from lawns, septic systems, historical agricultural land use, or some combination of these (Pickett and Cadenasso 2006).

Table 2 Mean (±SE) parameters (mg/L) for non-urban (<5% IS cover) and urban (>24% IS cover) watersheds in baseflow and stormflow. Data from Schoonover and Lockaby (2006)

Parameter	Baseflow		Stormflow	
	Non-urban	Urban	Non-urban	Urban
Cl^-	3.43 (0.13)	**9.46** (0.40)	2.87 (0.09)	**6.30** (0.32)
NO_3^-	0.61 (0.09)	**1.64** (0.16)	0.36 (0.07)	**1.93** (0.14)
SO_4^{2-}	1.58 (0.20)	**8.04** (0.58)	2.15 (0.13)	**6.86** (0.42)
Na^+	6.40 (0.67)	**10.01** (1.01)	5.14 (0.22)	5.17 (0.56)
NH_4^+	0.00 (0.02)	0.00 (0.03)	0.00 (0.01)	**0.15** (0.02)
K^+	2.45 (0.21)	**4.24** (0.51)	1.80 (0.05)	**3.28** (0.40)
Total P	0.08 (0.00)	0.09 (0.01)	0.08 (0.00)	0.09 (0.01)
DOC	2.44 (0.27)	**4.73** (0.47)	3.64 (0.22)	**5.52** (0.20)

Bold values indicate a significant difference ($p<0.05$)

Bacteria

Urban areas may have higher concentrations of bacteria due to elevated water temperatures and increased turbidity as bacteria survival increases with the opportunity to bind to sediment particles (Mallin et al. 2000; Schoonover and Lockaby 2006), as well as inputs to streams from inadequate municipal water treatment networks. Median fecal coliform concentrations were ~10× higher in urban streams than forested streams (2,750 vs. 261.5 MPN/100 mL for urban and forest respectively in stormflow and 1,500 vs. 112 MPN/100 mL for urban and forest respectively in baseflow) and were significantly related to discharge (Crim 2007). Fecal coliform concentrations were positively and negatively correlated with IS and forest cover respectively (Schoonover and Lockaby 2006; Crim 2007). Crim (2007) points out that "While fecal coliform bacteria indicate the possible presence of pathogens associated with fecal contamination, *E. coli* presence is definitive evidence of fecal contamination from warm-blooded animals". Median *E. coli* concentration ranges were higher in urban watersheds (135 to 1,255 MPN/100 mL) than in forested watersheds (94 to 169 MPN/100 mL and 59 to 170 MPN/100 mL for pine and mixed forest, respectively) (Crim 2007). Mallin et al. (2000) similarly found that both fecal coliform and *E. coli* concentrations were significantly related to % IS in tidal creeks of North Carolina.

Ecosystem carbon storage

Ecosystem carbon storage is greatly affected by changes in land use/cover. Zhang et al. (2008) modeled the changes in land use from 1974 to 2002 and the corresponding changes in carbon storage. According to their study, urban land in Muscogee, Harris, and Meriwether counties increased by 380% from 1974–2002 and impervious surfaces increased from 1.5% to 7.5% during the same period (Zhang et al. 2008). The net change in forested area during the study period was small due to the opposing processes of reforestation of abandoned cropland and deforestation for urban land. However, the carbon uptake with forest regrowth was slightly larger than the carbon lost from deforestation (23.0 $gC/m^2/yr$ vs. 18.4 $gC/m^2/yr$ respectively). Throughout the study period, the amount of carbon released due to urbanization increased while the amount of carbon released from conversion of forests to agriculture decreased. The authors suggest that as urbanization progresses in west Georgia, releases of carbon are likely unless forests are protected and/or restored (Zhang et al. 2008).

Invasive species and nutrient cycling

There are indications that invasion of Chinese privet into riparian forests (a factor associated with urbanization in the WestGa study area (Burton et al. 2005)) may lead to increased above- and belowground carbon sequestration in the short-term (Brantley 2008; Mitchell 2009). However, Brantley (2008) cautions that this effect may not persist because of the suppressive effect that Chinese privet has on woody regeneration of native species such as those that comprise the overstories of the riparian systems. Chinese privet was also associated with altered nutrient availability and efficiency, as the nitrogen nutrient use efficiency (N-NUE) of urban trees was lower than that of rural or developing trees (Mitchell 2009).

Contaminants in soil, lichens, and trees

Urban land uses can introduce air-borne contaminants to ecosystems which may be detected in plants and soils. Styers and Chappelka (2009) examined N, S, and heavy metal concentrations in lichens, trees, and soils along the urban-rural gradient in west Georgia. While soils and tree cores did not yield conclusive patterns for air-borne contaminants among land uses, significant differences were observed in lichen samples. For example, lichen tissue in urban plots had significantly higher ($p \leq 0.01$) concentrations of Cu, Pb, Zn, N, and S than in developing and rural plots. Although causal relationships cannot be determined from this study, roadways are a potential source of metals and N and S in urban areas.

Ecosystem structure

Riparian vegetation

Community structure

Land use change greatly alters the structure and composition of the riparian vegetation. Basal area of the regeneration layer of riparian forests in west Georgia decreased as forest cover decreased (Burton et al. 2005), which may indicate decreased productivity with disturbance. Leaf area index (LAI), stem density in the stand and regeneration layers, and midstory tree biomass were positively correlated with forest cover and negatively correlated with % IS (Table 3). Landscape diversity was highest in urban watersheds and patch density was highest in developing watersheds (Burton and Samuelson 2008). These indications of heterogeneity of urban landscapes corroborate the results of other studies (Zipperer et al. 2000). Alterations in soil properties such as moisture and water table depth may contribute to these observed changes in forest structure with urban development.

Urban riparian forests had significantly more non-native species than rural riparian forests in west Georgia (Burton et al. 2005; Loewenstein and Loewenstein 2005). For example, the urban sites and one developing site consisted of 20–33% non-native and the rural sites had 4–14% non-native species (Loewenstein and Loewenstein 2005). "The small size of many urban forest fragments and the associated high proportion of edge contribute to the susceptibility of these forest remnants to establishment of non-native plants whenever propagules are readily available" (Loewenstein and Loewenstein 2005). Burton et al. (2005) found that the most dominant species in the regeneration layer in urban, developing, and agricultural sites was the non-native, invasive *Ligustrum sinense* (Chinese privet). Loewenstein and Loewenstein (2005) reported that in addition to *L. sinense*, *Lonicera*

Table 3 Correlation coefficients between impervious surfaces (%) and forest cover (%) and structural indices. Modified from Burton and Samuelson (2008)

Structural index	Impervious surfaces	Forest cover
Stand density	**−0.61**	**0.58**
Regeneration density	**−0.79**	**0.70**
LAI	**−0.50**	**0.54**
Total aboveground biomass	0.15	−0.34
Overstory biomass	0.14	−0.32
Midstory biomass	−0.44	0.41
Shrub biomass	0.15	−0.18
Basal area	0.12	−0.27
Quadratic mean diameter	**0.49**	**−0.53**

Bold values indicate a significant difference ($p < 0.05$)

Density (number of native stems/ha); *LAI* leaf area index (m^2/m^2); *aboveground biomass* (Mg dry weight/ha); *basal area* (m^2/ha); *Quadratic mean diameter* (cm) *japonica* (Japanese honeysuckle) and *Microstegium vimineum* (Nepalese browntop) were prevalent in all watersheds.

With increasing urbanization in west Georgia, plant richness decreased linearly (Burton et al. 2009) and Shannon diversity in the regeneration layer also decreased (Burton et al. 2005). However, Loewenstein and Loewenstein (2005) did not find a significant difference in species richness, average richness, or species density among land use types. They did find that *L. sinense* and *M. vimineum* were negatively correlated with overstory reproduction, indicated by the number of seedlings, and overall species richness (Loewenstein and Loewenstein 2005). Similarly, non-native woody plants were negatively correlated with riparian woody plant diversity in Burton et al. (2005).

Plant traits

Burton et al. (2009) aimed to identify trait differences between urban and rural plants in west Georgia. This study found that urban sites were characterized by the following traits: evergreen leaf type, fast growth rates, shallow rooting depth, and to a lesser extent, animal seed dispersal, shrub plant form, intermediate shade tolerance, and medium life span. Evergreens, such as *L. sinense*, have lower rates of photosynthesis, nutrient loss, and decomposition and therefore could be advantageous in disturbed sites. Disturbance has opened gaps in the canopy and thus plants with intermediate shade tolerance do well in urban sites. Animal seed dispersal is beneficial because the seeds can be carried further and are more likely to find suitable habitat for growth. In contrast to the above plant traits, rural sites were characterized by deciduous leaf type, water or gravity seed dispersal, midstory tree form, shade tolerance, slow growth rate, deep rooting, and long life span (Burton et al. 2009).

Hydrological changes associated with land conversion can alter vegetation communities. In urban areas, flood intolerant plants were found in the regeneration layer and flood tolerant plants were found in the forest stands (Burton et al. 2009). While the presence of flood intolerant plants in the regeneration layer of urban sites may seem counterintuitive, it may actually be beneficial. These plants are easily killed in floods, but then they reestablish and grow quickly when the flood has subsided.

Fauna

Coyotes

Wildlife may be affected by urban development and resulting habitat alterations. Billodeaux (2007) studied coyotes among land uses in west Georgia. Coyotes were present at around 30% of the sites studied and no differences were found in coyote use between rural and suburban/urban land uses. This suggests that coyotes have been able to adapt to altered habitats in urban and suburban areas of west Georgia. Biological season differences were observed for coyote detection, however, with the lowest detection rates in summer when pups are reared. Increasing the duration of the study and the number of sites of detection may help to elucidate coyote behavior and utilization as development progresses in west Georgia.

Birds

Urban development is believed to be the most important factor contributing to endangered species in the U.S. As an example, Stratford and Robinson (2005) found that urbanization, measured by increases in urban cover or edge contrast, negatively affected the species richness of neotropical migratory birds in western Georgia. A threshold for urbanization was observed, as almost all species were associated with areas with little urban development (<15% urban cover—impervious surfaces such as roads and housing) (Stratford and Robinson 2005). While other studies have found local variables to be more important than regional variables (Clergeau et al. 2001; Jokimäki and Kaisanlahti-Jokimäki 2003), this study found large- and medium-scale habitat attributes to be some of the best predictors of migratory bird species richness. For example, in 2002, one of the best predictors of species richness was large-scale urban cover (negative effect) and in 2003, one of the best predictors was large-scale transitional cover (positive effect) (Stratford and Robinson 2005). The authors suggest that a useful conservation measure for migrant birds would be to protect the areas with low urban cover and preserve large forest sections within the urban landscape.

Amphibians and reptiles

Barrett and Guyer (2008) examined amphibian and reptile populations among different land uses. According to this study, total herpetofauna species richness showed no difference among land uses in west Georgia watersheds. However, urban watersheds had fewer amphibian species than all other land uses, but significantly more reptile species. Specifically, urban watersheds lacked all salamander species except *Eurycea cirrigera* and all hylid frogs which require slow-flowing streams for breeding, but contained four species of snakes and four species of turtles that were not found in the other watershed types. The authors attribute the assemblage changes to the alterations in hydrology and riparian forests. Small streams that once had closed-canopies and shallow flowing water were changed into open-canopies and deep water through channel incision in urban areas. The loss of woody vegetation and emergence of open canopies in urban streams may have led to desiccation and decreased survivorship of amphibians. In contrast, reptiles may be better suited for urban streams because they can more easily re-colonize and their eggs have better protection.

Fish

Similar to amphibians and reptiles, fish are directly affected by physical changes in habitat associated with land use conversions such as altered hydrology, channel morphology, and stream temperature, light, sediment, and nutrients. Helms et al. (2005) studied fish assemblages in west Georgia among different land uses and found that with increasing urbanization, the GA index of biotic integrity (GA-IBI) declined. An increase in fish with eroded fins, lesions, and tumors suggested that fish health also declined in urban streams. Ordination displayed pronounced differences between the fish assemblages of forested vs. urban streams while assemblages in agricultural (pasture) and developing streams fell between those of forested and urban streams. Tolerant species such as centrarchids were commonly found in urban streams, while the proportion of lithophilic spawners (generally sensitive species) decreased compared to forested streams. Also, the % IS was used as an explanatory variable and a strong positive relationship was found with the % herbivores in summer (R^2=0.46) and winter (R^2=0.64). This has implications for water quality because algal blooms may occur with increased nutrients from urban land use, thus increasing the food base for herbivores. Seasonal variation was observed as natural basin variables were better predictors of fish assemblages in winter and spring than land use, while land use variables were better predictors during summer (Helms et al. 2005).

Summary and conclusions

Urban studies are becoming increasingly important due to rapid population growth and expansion of urban land globally. The WestGa project provided a fairly comprehensive overview of the socioeconomic drivers of and environmental responses to urbanization associated with a mid-size city within a 6-year timeframe. It is apparent that rising land values, increased market concentrations, increased road accessibility, and ultimately, higher opportunity costs for maintaining forested land contributed to the conversion of forested to urban land and resulted in degradation of aquatic and terrestrial systems in west Georgia. These same cultural and socioeconomic factors associated with increased urbanization are likely to continue in the southeastern United States and are common globally.

Multiple ecological responses to urbanization were observed with alteration of hydrological regimes having perhaps the most profound effects. Changes in hydrology induced a cascade of terrestrial and aquatic impacts such as changes in stream nutrients and sediment, riparian vegetation, fish, amphibians, and reptiles. The patterns of altered hydrology including more flashy discharges in urban streams are direct effects of vegetation clearing and incorporation of impervious surfaces. Therefore, to minimize the impacts of urbanization on ecological processes, consideration should be given to limiting the impervious cover and planning the spatial distribution of urban vs. forested land within the watershed. Maintenance of riparian forests can alleviate some of the pressure from increasing urban development.

Degradation of water quality can have far-reaching implications. Increased stream sediment, nutrients, and bacteria can render some water resources unfit for particular uses (drinking, recreation, habitat maintenance, etc.) and thereby limit the available water for humans and aquatic (and riparian) life. Furthermore, there are health concerns with elevated levels of nutrients, bacteria, and metals in water resources which again apply to both human and aquatic life. Fish populations in west Georgia streams have already registered some of these effects, indicated by an increase in tumors, lesions, and eroded fins.

The composition of both fauna and flora assemblages was altered by urbanization in watersheds of west Georgia. Riparian vegetation in urban areas has more non-native species, but lower overall species richness. Tolerant or generalist fish species are more common than sensitive species in urban streams. Amphibian abundance declined while reptile abundance increased. The cumulative effects of these simultaneous changes have not been examined and could have profound impacts on ecosystem function. Changes (losses or introduction) in even one species or functional group have been known to induce changes throughout multiple trophic levels (Chapin et al. 2002).

While other studies have suggested that the effects of urban development may be seen at around 10–20% IS (Paul and Meyer 2001; Calhoun et al. 2003), these studies in the west Georgia Piedmont showed that effects can be observed at even lower levels of urban development (<5% IS). Also, it is clear from these results that water quality degradation can occur rapidly during the first stages of urban development. Together, these findings suggest that caution must be used from the earliest stages of construction and development with even small increases in impervious surfaces to limit ecological disturbance of the landscape.

In addition to impervious cover (%), the issue of scale is also important as study areas of different sizes may have varying levels of disturbance. For example, a large watershed with 20% IS may have a greater total inputs of nutrients and waste to streams than a small watershed with 20% IS. Impervious cover induces a suite of influences on ecosystem structure and function, but agricultural and industrial uses have their own signatures. The interactions of multiple land uses within the watershed may be non-linear (de la Crétaz and

Barten 2007). Furthermore, ecosystem structure and function may be influenced by legacy effects of past land uses. Therefore, the heterogeneity and size of the study area, as well as historical context, must be accounted for in the evaluation of the effects of land use on ecosystems.

With regard to the potential for negative, socioeconomic feedbacks to occur as a result of environmental degradation, it was found that residents of developing and urban areas had less environmental awareness than their rural counterparts. This combined with a general lack of outreach mechanisms for transferring environmental impact information to residents suggested that the potential for negative feedbacks to alter the rate or nature of urbanization was low. Consequently, we rejected our hypothesis and suggest that environmental conditions had little influence on rates and patterns of development. This finding emphasizes the critical need for increased environmental outreach efforts aimed at the general population of urbanizing landscapes.

The socioeconomic drivers of land use change including population growth and increases in per capita income will drive a demand for more land for urban uses in the coming years. Quantified ecological responses to development along the urban-rural gradient can help to predict the changes that will occur with increasing urbanization in the west Georgia Piedmont. An understanding of both the socioeconomic drivers of and ecological responses to land use change is critical for facilitating sustainable development. Planning and land use policy officials could benefit from incorporating this and other similar studies into their decision making process to encourage economic and ecological welfare.

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