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The influence of low-intensity watershed development on the hydrology, geomorphology, physicochemistry and macroinvertebrate diversity of small coastal plains streams

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ABSTRACT

Coastal areas are under increasing pressures from human population growth and expansion, resulting in widespread conversion of forested and agricultural lands to low-density residential development. We investigated stream response to urban land use in 13 small coastal watersheds with low-levels of impervious surface cover (IS, 1.5 – 10.9%). Specifically, we examined putative mechanistic relationships between pre-selected land-cover categories (riparian forest, agriculture and IS) and stream hydrology, geomorphology, and water-chemistries. We further examined relationships between commonly used benthic macroinvertebrate response metrics, land-cover variables and potential environmental stressors. We used partial least squares (PLS) regression, which has been shown to perform well for model selection and parameter estimation in small sample and collinear situations. Physicochemical variables total phosphorus (TP), total suspended solids (TSS), specific conductivity (SPC), pH and median water temperature were significantly associated with both% riparian forest buffer (FB) and% IS. Storm-event frequency and a baseflow index were associated with% IS alone; in contrast, % FB and IS were significantly associated with hydrologic flashiness and bankfull width. Benthic macroinvertebrate density was associated with% IS and associated hydro-geomorphic stressors, benthic diversity (richness, *H*', evenness) and taxa sensitivity/tolerance metrics (% EPT, NCBI) were more strongly associated with maximum water temperatures, gradients of organic matter and flow permanence in these streams than anthropogenic land-cover or associated stressors.

KEY TERMS: land-cover, collinearity, hydrology, nutrients, macroinvertebrates, stream

1. Introduction

Deforestation and human activity in watersheds can be highly influential to stream ecosystems (Allan, 2004; Walsh et al., 2005). Forested lands, specifically riparian forests, are thought to act as material sinks and natural physical filters, mechanistically linked to in-stream sediment and nutrient concentrations (Naiman and Décamps, 1997). Changes in physicochemical conditions have been observed in relation to both agricultural and urbanized watersheds, as both act as sources for nutrients, sediment, and other pollutants (Paul and Meyer, 2001; Allan, 2004; Walsh et al., 2005; O'Driscoll et al., 2010; Mogollón et al., 2016). Urbanization is a particularly influential land-use/cover (LULC) type that is characterized by relatively high levels of impervious surface (IS) cover, which can directly alter watershed hydrology (Brabec, 2002; Brown et al., 2009). Impervious surface has been shown to increase flood magnitude and frequency, increase the rate of change in discharge ('flashiness'), and decrease flood duration (Rose and Peters, 2001; Poff et al., 2006; Schoonover et al., 2006; Brown et al., 2009; Morrison, 2010; O'Driscoll et al., 2010). Stream benthic macroinvertebrates are a diverse group of organisms exhibiting a wide range of environmental tolerances and are frequently used as indicators of stream ecosystem health. Benthic richness, diversity and the proportion of sensitive taxa are typically lower in urbanized streams compared to more forested sites (Norris and Thoms, 1999; Paul and Meyer, 2001; Walsh et al., 2005; Wenger et al., 2009).

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Impacts of urban development on streams are generally greater and more detectable at a much lower areal proportion compared to impacts from agriculture (Allan, 2004). Generalized urban land use thresholds (below which negative impacts are not detected; e.g. <10%) have been suggested, but these purported thresholds may misrepresent what is likely a continuum of impacts on stream ecosystems, even at low urban cover (Brabec, 2002; Shuster et al., 2005). To date, most urban studies have focused on relatively high levels of urban development; however, low-density urban development may be more common and actually encouraged by LULC policies (Cunningham et al., 2009; Chadwick et al., 2011). Lower levels of urban development have recently gained research attention as impervious cover of <10% has been associated with changes in stream hydrology, physicochemistry, and a reduction in species richness (Burcher and Benfield, 2006; Schiff and Benoit, 2007; Lussier et al., 2008; Cunningham et al., 2009; Nagy et al., 2012). A few studies have detected macroinvertebrate assemblage responses to much lower urbanization levels (≤ 4.4% ISC) (Wenger et al., 2009); however, research regarding low-level urban development is generally limited, thus additional research is necessary to form generalities regarding abiotic and biotic responses.

It has been suggested that the magnitude of hydro-geomorphic response to watershed urban land use may be lower in the coastal plains relative to higher gradient physiographic regions (Nagy et al., 2011; Utz et al., 2011). Lower topographic relief and more extensive riparian wetlands have been considered possible reasons for why coastal plain streams may be less responsive to urbanization than piedmont streams (Utz et al., 2011). Virtually all of the coastal plains land area in the U.S. has been altered by human activity over the last 2 centuries with more recent conversions generally from forested/agricultural land to urban land (Nagy et al., 2011; O'Driscoll et al., 2010; Smock and Gilinsky, 1992). In historically agricultural areas, it is possible that low-density urbanization may not be influential enough to yield detectable changes in hydrogeomorphology or physicochemistry (Burcher and Benfield, 2006). Coastal plains watersheds are typically low-gradient with sandy soils, possess relatively low runoff-rainfall ratios, and thus have lower potential for particle entrainment, hydrologic alteration, and geomorphic change than high-gradient upland watersheds (Feeley, 1992; Nagy et al., 2011, 2012). It might be predicted that lower levels of development would not lead to detectable changes in low-gradient coastal streams, especially where agricultural activities were prevalent; however, IS cover ≤ 10% has been shown to influence stream hydrology and physicochemistry in some coastal areas (Schiff and Benoit, 2007; Lussier et al., 2008; Cunningham et al., 2009; Nagy et al., 2012).

Coastal areas worldwide are under increasing pressures from human population growth and land development (Nagy et al., 2011). Based on analyses from the National Land Cover Database (NLCD) impervious surface product, roughly half of the urban LULC change along the U.S. Gulf of Mexico in the past 2 decades has occurred within 50 km of the coast, and the dominant LULC change from the Florida panhandle to Louisiana has been low-intensity (e.g., suburban, urban-sprawl) development (Xian et al., 2012). The Southeast has led, and is predicted to lead U.S. regions in developed LULC and population growth into 2030, and low-density development is predicted to continue along the coast of the Gulf of Mexico (Wear and Greis, 2002; Alig et al., 2004; White et al., 2008; Nagy et al., 2012; Xian et al., 2012). Thus, there is an urgent need to understand and predict impacts of low-density development on stream ecosystems along the Gulf Coast and in the Southeast in general.

The goal for our study was to determine if empirical evidence suggests that low-density development influenced the hydrology, geomorphology and/or physicochemistry, and biotic communities of streams draining small coastal plains watersheds. Specifically, we described relationships between watershed LULC, potential in-stream stressors and commonly used macroinvertebrate assemblage metrics. Because of the extensive history of agriculture in this area, we hypothesized that the low levels of IS present in study watersheds would have little influence on the hydrogeomorphology, physicochemistry, and benthic assemblages of these study streams.

2. Methods

2.1. Study area

Thirteen wadeable, 1st- to 3rd-order (based on Strahler stream order classification, (Strahler, 1957), non-tidal (salinity range: 0.02 – 0.04) study stream reaches were selected along a gradient of low IS within or adjacent to the Wolf Bay Basin in coastal Alabama, USA (Fig. 1). This region is characterized by low-gradient, sandy-bottom streams that differ from much of the interior U.S. with regards to several potentially important characteristics including higher annual precipitation levels and rainfall:runoff ratios, and shorter recurrence intervals for bankfull events (0.19–1.0/y) (Sweet and Geratz, 2003; Hardison et al., 2009; Metcalf, 2009; Nagy et al., 2011). Study sites spanned gradients of low IS (1.5–10.9%), agriculture (15.3–52.9%), and riparian forest cover (27.8–95.5%, Table 1). To minimize proximate effects of roads, sites were chosen to be upstream of the nearest stream-road intersection, the typical access point.

A 10-m digital elevation map (DEM;Source: USGS) and 0.15-m resolution aerial photographs (2009) of Baldwin County, Alabama were used to quantify LULC in stream watershed. Watershed catchments were defined using DEM and ArcHydro (Environmental Research Systems Institute, Inc., Redland, California) and contained all land area upstream of sampling reaches. LULC classification was achieved by manual digitization of aerial photographs in ArcGIS (Environmental Research Systems Institute, Inc., Redlands, California). LULC categories were chosen that could be theoretically directly linked to in-stream conditions: % IS cover (e.g. buildings, paved roads), % agriculture (Ag), and% riparian forest buffer (FB) in a commonly used streamside buffer width of 100 m (Allan, 2004; Burcher et al., 2007). An accuracy assessment was performed on a random selection of 25% of the 21 K total LULC polygons created by manually confirming the LULC category assigned.

2.2. Response variables

2.2.1. Channel and floodplain geomorphology

Several aspects of stream-channel and floodplain geomorphology were quantified with 3 cross-sectional surveys taken in low flow months (summer 2009) at each stream in close proximity to the in situ stage recorders (described below). Detailed width and depth measurements were made in the approximate bankfull channel and average floodplain slope perpendicular to the active channel was derived from field measurements and 10 m DEM maps using GIS. Bankfull stage was determined as the stage level corresponding to the minimum ratio of width to depth (Pickup and Warner, 1976) and used to estimate bankfull depths and widths. Environmental extremes in geomorphology may be more biologically/ecologically relevant, so maximum flood cross-sectional dimensions (width and depth) were estimated (for relation to benthic metrics) from 1-dimensional models created from time-series stage data and data from cross-sectional surveys.

2.2.2. Hydrology

A suite of hydrologic variables was calculated using stream stage and discharge data. Solinst pressure transducers (Levelogger Gold, model 3001) were installed at each site to quantify water stage

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