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Synergistic use of Landsat Multispectral Scanner with GIRAS land-cover data to retrieve impervious surface area for the Potomac River Basin in 1975

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ABSTRACT

For many studies of urbanization, particularly those covering broad spatial extents and thus requiring the perspective afforded by satellite remote sensing, the longest time series of impervious surface area (ISA) initiate with the availability of Landsat Thematic Mapper (TM) data in the mid 1980s. Earlier generation remote sensing data, such as Landsat Multispectral Scanner (MSS) do not generally lead to robust representations of impervious surface area due to poor spectral differentiation between impervious and non-impervious surfaces lacking vegetation. In the 1970s, however, the USGS completed a comprehensive mapping of land cover based on aerial photography called the Geographic Information Retrieval and Analysis System (GIRAS). In this paper we describe a methodology for retrieving ISA estimates through the fusion of GIRAS land cover with historic and contemporary remote sensing data, resulting in a data set that is temporally comparable to more modern data sets (e.g. the National Land Cover Database (NLCD) ISA product). We calculate correlation coefficients between our data set and digitized aerial photography at 4 spatial resolutions, exhibiting a maximum correlation of 0.65 at 120-m and 240-m pixel sizes. Our highest resolution product (30-m) exhibited 94% accuracy and a kappa coefficient of 36% in rural areas, and 90.7% accuracy and a kappa coefficient of 59.6% in suburban areas. Further, we show that trends in urban area through time derived from these data exhibit accelerating rates of development throughout the Potomac River basin 1975–2001, including increased development in riparian buffer zones and on steeper topography. These results are applicable wherever low-resolution vector-based data sets of urban area are available or could be generated for the pre-Landsat TM era.

1. Introduction

Rapid urbanization in many regions of the world has led to an array of environmental concerns. These include impacts to air and water quality (Jennings & Jarnagin, 2002; Wollheim et al., 2005), regional climate change (White et al., 2002; Yuan & Bauer, 2007), and the loss of biological and other natural resources (Goetz & Fiske, 2008; Jantz et al., 2005; Snyder et al., 2005). Remote sensing offers a consistent framework for representing spatial patterns and rates of urbanization over time through accurate observations of impervious surface area (ISA; e.g., paved surfaces and roof tops) and classifications of urban land cover (typically associated with a threshold ISA.) Maps of impervious surface area have been used for urban planning (Arnold & Gibbons, 1996), watershed studies (Jennings & Jarnagin, 2002), and to parameterize urban growth models (Jantz et al., 2004). Encouraged by their many uses, research has led to improved methods for generating ISA data products with greater accuracy (Ji & Jensen, 1999; Walton, 2008; Weng & Hu, 2008; Weng et al., 2008; Yuan et al., 2008; Zoran et al., 2008), and the effective utilization of longer ISA data records for trend analysis (Jennings & Jarnagin, 2002; Powell et al., 2008).

In much of the United States, the last several decades of the 20th century were characterized by rapid expansion in new housing and transportation infrastructure, and are therefore associated with an increase in impervious surface area (Batisani & Yarnal, 2009; Jantz et al., 2005; Theobald et al., 2009). The nature of this expansion has been examined in the context of natural resource loss and the potential impact of urbanization on watersheds in particular. For example, it is widely thought that increased impervious surface area adjacent to streams (i.e., reducing riparian buffer zones (Goetz, 2006; Mayer et al., 2006) or burying streams altogether (Elmore & Kaushal, 2008)), results in disconnecting streams from their floodplains and reduced stream functioning (e.g., denitrification potential (Groffman & Crawford, 2003; Kaushal et al., 2008)). Another landscape feature that is thought to influence the probability of urbanization is topographic slope (Claggett et al., 2004; Jantz & Goetz, 2005), but this influence is likely to change over time as level building sites become more rare. These ideas have been incorporated into modeling efforts that attempt to predict future urbanization and its impact based on patterns of past growth in relation to topography (Carlson, 2004). However, these models and impact

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studies are generally limited by the availability of impervious surface area data for the period prior to the Landsat Thematic Mapper era (circa 1984). This is due to the fact that with few exceptions (Gillies et al., 2003; Powell et al., 2008), remote sensing of ISA has been restricted to the span of time covered by Landsat Thematic Mapper (TM) data. This is likely an important problem, in that just as Landsat TM was beginning to deliver data, urbanization was rapidly expanding; yet we have limited means to investigate how patterns and impacts of urbanization were changing through this period.

Here we describe a method for generating 1975 ISA data. In overview, the method leverages on the strengths of two very different data sources available for this period. The first source is the Geographic Information Retrieval and Analysis System (GIRAS) (Mitchell et al., 1977; Price et al., 2003), which is a vector-based land cover and land-use (LCLU) data base generated from technician interpretation of aerial photographs. The second is Landsat Multi-spectral Scanner (MSS) data, which is available through the 1970s and early 1980s at 60-m resolution. We validated our products against digitized aerial photography at 4 spatial resolutions and examine some useful trends with more recent ISA data, including the rate of development adjacent to streams and on steep topography.

2. Methods

2.1. Site description

The Potomac River basin (PRB) was chosen as an experimental landscape for which to build and validate 1975 Urban/ISA data products. The physiographic setting of the PRB spans a landscape continuum from mountains to the sea; has landscape diversity both in terms of geomorphology and land use; and has rapid population growth (Jantz et al., 2004). The basin spans all 5 of the physiographic provinces characteristic of the mid-Atlantic region: the Coastal Plain, the Piedmont Plateau, the Blue Ridge Mountains, the Ridge and Valley, and the Appalachian Plateau (Fig. 1). The Potomac River serves as the major water source to the large metropolitan population of the United States' capital, is the second largest source of freshwater input to the Chesapeake Bay, and is perceived to be highly sensitive to climate and land-use changes (Jaworski, 1993; Jaworski et al., 1992). As such, it likely represents much of the eastern US, and urban area and ISA maps of this region have broad future applicability to understanding the impact of and interactions between urbanization and climate change (Lookingbill et al., 2009).

Table 1
Data sets used in this paper.

Date	Name	Description
1970–75	GIRAS LULC	Digitized aerial photographs acquired between 1970 and 1975 (for the mid-Atlantic region.) Urban area was defined as the union of the developed and transportation classes. Acquired from: http://eros.usgs.gov/products/landcover/lulc.php
1972–79	Landsat MSS	9 scenes, paths 16–18 and rows 32–34. Scenes from 1978 and 1979 were used for ~20% of the study area; remaining data were from 1972 to 1976.
1970–74	Aerial photography	High resolution (~1 m/pixel) digitized aerial photography was acquired from numerous sources, including state and local governments.
1990	MA-RESAC 1990	Continuous field representation of ISA (1–100%) produced from Landsat TM data and decision tree classification (Jantz et al., 2005).
2001	NLCD 2001	Continuous field representation of ISA (1–100%) produced from Landsat ETM+ as part of the National Land Cover Dataset. Acquired from: http://www.mrlc.gov/nlcd_multizone_map.php

2.2. MSS data and processing

MSS data from circa 1975 were acquired (Table 1) and processed for vegetation cover using spectral mixture analysis (SMA; (Adams et al., 1986; Elmore et al., 2000; Small, 2004)). Pre-processing steps ensured that vegetation fractions calculated from SMA were comparable across multiple MSS images and differentiated terrain. Specifically: (1) georeferencing was performed at the USGS prior to downloading the data (L1T level of systematic geometric accuracy), (2) dark object subtraction using a clear lake was used to account for varying amounts of

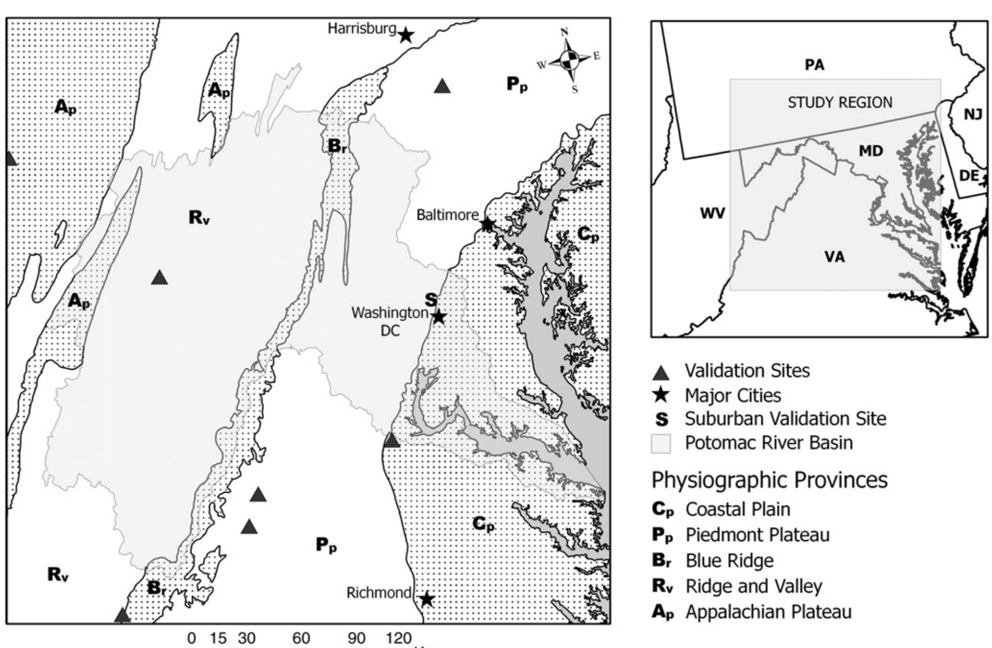

Fig. 1. The study area and location within the mid-Atlantic region. The study area and seven validation sites cover 5 physiographic provinces and the Potomac River Basin. The Chesapeake Bay dominates the eastern third of the study area. The total area of all aerial photographs used in validation was 65.82 km^2. The total area of the study region is 109,762 km^2.