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Urbanization as a land use change driver of forest ecosystem services

S. Delphin[a,1], F.J. Escobedo[b,*], A. Abd-Elrahman[c], W.P. Cropper[d]

[a] School of Forest Resources and Conservation, University of Florida, 350 Newins Ziegler Hall, PO Box 110410, Gainesville, FL 32611, USA
[b] School of Forest Resources and Conservation, University of Florida, 361 Newins Ziegler Hall, PO Box 110410, Gainesville, FL 32611, USA
[c] Geomatics Program, School of Forest Resources and Conservation, University of Florida, 1200 N. Park Road, Plant City, FL 33563, USA
[d] School of Forest Resources and Conservation, University of Florida, 214 Newins Ziegler Hall, PO Box 110410, Gainesville, FL 32611, USA

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ABSTRACT

Land use change in the form of urbanization is a direct driver affecting the provision of ecosystem services from forests. To better understand this driver, we modeled the effects of urbanization on three regulating and provisioning ecosystem services in two disparate watersheds in Florida, USA. The study integrated available geospatial and plot-level forest inventory data to assess future changes in carbon storage, timber volume and water yield during a period of 57 years. A 2003–2060 urbanization and land use change scenario was developed using land cover data and a population distribution model. The Integrated Valuation and Ecosystem Services Tradeoffs model was then used to quantify changes in ecosystem services. Carbon storage was reduced by 16% and 26% in the urbanized 2060 scenario in both the rural Lower Suwannee and urban Pensacola Bay watersheds, respectively. Timber volume was reduced by 11% in the Lower Suwannee and 21% in the Pensacola Bay watershed. Water yield, however, increased in both watersheds by 4%. Specific sub-watersheds that were most susceptible to urbanization were identified and mapped and ecosystem service interactions, or trade-offs and synergies, are discussed. Findings reveal how urbanization drives the spatio-temporal dynamics of ecosystem services and their trade-offs. This study provides policy makers and planners an approach to better develop integrated modeling scenarios as well as designing mapping and monitoring protocols for land use change and ecosystem service assessments.

1. Introduction

The world's population is rapidly increasing (US Census Bureau, 2013) and the world's population is projected to be 9 billion by 2050. This population increase will lead to land use and cover (LULC) changes and alter the provision of ecosystem services such as food, timber, and clean water (European Commission, 2009; Hoyer and Chang, 2014; Millennium Ecosystem Assessment, 2003; Vitousek et al., 1997). Urbanization, the development of new urban areas from non-urban lands, is a key anthropogenic driver affecting ecosystems (Bengston et al., 2005; He et al., 2016; Yue et al., 2013; Zhang et al., 2012). The use of the driver concept in influencing land use change and ecosystem services, has become a common approach for studies analyzing policies and management objectives and associated effects on human well-being (Hoyer and Chang, 2014; Yue et al., 2013). By analyzing ecosystem service drivers using integrated modeling scenarios, as well as measured and available data, we can better understand ecosystem function and changes in their services. We can also provide information for planning and policy formulation in order to minimize potential negative impacts to human well-being (Millennium Ecosystem Assessment, 2003).

Forests are important for carbon storage and this function is referred to as a *regulating ecosystem service* as it regulates global climate (Millennium Ecosystem Assessment, 2003). Forest carbon storage is commonly measured according to four pools: above-ground biomass, belowground biomass, litter or dead biomass, and soil (Ashton et al., 2012). Indeed, forests are critical to the global carbon cycle as they comprise a large stock of carbon relative to other ecosystems; thus conserving peri-urban forested areas from urbanization is a priority (Gorte, 2009; Harmon, 2001; Jandl et al., 2007; Yonavjak et al., 2011). Urbanization of forests in the southern U.S. has for example resulted in about 0.21 Petagrams (Pg) of carbon emissions from 1945 to 2007 (Zhang et al., 2012). Zhang and

* Corresponding author. Current address: Functional and Ecosystem Ecology Unit-Biology Program, Faculty of Natural Sciences and Mathematics, Universidad del Rosario, Kr 26 No 63B-48, Bogotá D.C., Colombia.
E-mail addresses: soniadelphin@gmail.com (S. Delphin), fjescobe@gmail.com, franciscoj.escobedo@urosario.edu.co (F.J. Escobedo), aamr@ufl.edu (A. Abd-Elrahman), wcropper@ufl.edu (W.P. Cropper).
[1] Current address: World Wildlife Fund, Edificio Opa Rudy-4to piso, Avda. Argaña casi Avda. Perón, Asunción, Paraguay.

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Nagubadi (2005) also found that urbanization is one of the principal drivers in the decline of natural forest timber areas. Urban areas can store carbon in the form of planted and remnant trees; but, 70–100 years are needed before pre-urbanization carbon stocks are reached (Zhang et al., 2012). Furthermore, the recovery of carbon stocks to pre-urbanization levels is uncertain and depends on the specific ecosystem, its structure and management of the existing urban forest.

As such, timber supplies are significantly affected by urbanization. Timber products are considered a *provisioning ecosystem service* that provides direct benefits to people (Boyd and Banzhaf, 2007; Millennium Ecosystem Assessment, 2003). The benefits of these provisioning ecosystem services (e.g., timber, food, non-timber forest products, water supply) are widely recognized and are more easily valued than most other ecosystem services because of the existence of markets (De Groot et al., 2010). For example, forests in the Southern U.S. produce more than 60% of the nation's timber products and substantially contribute to the region's economy (Prestemon and Abt, 2002a). Bystriakova et al. (2005) report that timber harvesting at the global scale has increased by 60% in the last four decades and the increasing trend is expected to continue, but at a slower rate. Further, Cubbage et al. (1995) found that urbanization reduced timber supply, especially of softwoods and similarly Hodges et al. (1998) has documented how forest-timber areas in Louisiana, U.S. have been reduced by urban development.

Water is another valuable forest *regulating and provisioning ecosystem service* (Kreye et al., 2014). Land use changes can however alter the quantity and quality of water (Foley et al., 2005; Sun et al., 2005); therefore, determining the effect of forest LULC changes on water yield and quality is an important consideration. Water yield is the sum of annual precipitation that does not evaporate from soil and water or transpire from vegetation (Mendoza et al., 2011). Since urban areas increase runoff, as a result of decreased interception, evapotranspiration and infiltration, they can decrease water quality and increase overall water yield (Arnold et al., 1987; Hanson et al., 2010). Indeed several studies have determined the relationship between the hydrological cycle, forests (Bosch and Hewlett, 1982; Sun et al., 2005), and urbanization. Hollis (1977) reports that median flow increased by approximately 40% post- urbanization in the Canon's Brook catchment in England. Arnold et al. (1987) also modeled the effect of urbanization on water yield in a rural Texas U.S. watershed that urbanized over 70 years to about 77% urban land cover and found that annual surface runoff would increase by about 10%. Other studies in Florida, U.S. have analyzed the effect of urbanization on water quality (Cooley and Martin, 1979; Frick, 1998) and water supply (Boggess, 1968). However, we found no other relevant studies on the effects of urbanization on forest water yield or timber production in the State of Florida.

Geographic Information Systems (GIS) models have been used to assess the potential effects of different drivers on the provision of ecosystem services in subtropical forests (Cademus et al., 2014; Metzger et al., 2006). Timilsina et al. (2011), for example, used geospatial models to map forest carbon storage hotspots in Florida U.S. and identified plot-level ecological and anthropogenic drivers of this *regulating ecosystem service,* based on the Millennium Ecosystem Assessment (2003) classification. Cademus et al. (2014) also used geospatial and forest inventory data to assess interaction or the trade-offs (win-lose situations), synergies (win-win situations) and drivers in pine dominated forests in Florida. Models such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) developed by the Natural Capital Project (http://www.naturalcapitalproject.org/), have also used available geospatial data to estimate and map the provision of ecosystem services (Tallis et al., 2011). The model estimates the provision of ecosystem services in a current land use/cover and in different scenarios that incorporate proposed policies, management goals and disturbance regimes.

Because of this, the InVEST model has been recently used to quantify and value ecosystem services and thus facilitate their integration into policy making (Daily et al., 2009; Hoyer and Chang, 2014; Tallis et al., 2011). Daily et al. (2009) and Nelson et al. (2009) have applied InVEST in different areas of the US, and He et al. (2016) in China, to assess the effects of alternative land use and management decisions on ecosystem services. Hoyer and Chang (2014) estimated the provision of freshwater ecosystem services for two basins in Oregon using several urbanization and climate change scenarios. Delphin et al. (2013) and Bottalico et al. (2016) also analyzed the effect of a driver (i.e., hurricanes) and forest management scenarios, respectively, on two ecosystem services, timber and carbon stocks, using the InVEST and other geospatial models. Approaches such as those of Delphin et al. (2013), Bottalico et al. (2016), He et al. (2016); and Hoyer and Chang's (2014) could therefore be adapted to assess both the spatial and temporal effects of urbanization on multiple ecosystem services and their interactions as well as to better formulate land use policies.

Given the lack of studies on the effects of ecosystem service drivers on subtropical forest ecosystem service provision, the aim of our study was to assess the effects of urbanization on a bundle of forest ecosystem services and their trade-offs: carbon storage as an indicator of climate regulation, water yield as an indicator of flooding regulation, and timber volume, as an indicator of a provisioning service. Our specific objectives were to quantify both the temporal and spatial effects of urbanization on these key ecosystem services from 2003 to 2060 using: (1) the InVEST model, (2) plot-level United States Department of Agriculture (USDA) Forest Inventory and Analysis (FIA) data, and (3) a regional forecasted urbanization land cover change scenario for 2003–2060 based on a population distribution spatial model.

We used the rural Lower Suwannee River and urbanized Pensacola Bay watersheds in northwestern Florida U.S. as our two study areas. These two representative, yet disparate in terms of rural versus urban land uses, study watersheds were selected based on: the proportion of forest and urban land covers, FIA plot density, and the presence of impaired water bodies (i.e., do not meet water quality standards) according to Florida's Statewide Comprehensive Verified List of Impaired waters (http://www.dep.state.fl.us/water/watersheds/assessment/a-lists.htm). This integrated modeling approach using two subtropical watersheds should contribute to policy-relevant land management and planning assessments. It can also be used to better communicate the temporal and spatial effects and trade-offs of urban development and other land use changes on ecosystem services in other types of forested ecosystems in the world.

2. Material and methods

2.1. Study areas

The rural Lower Suwannee River watershed in western Florida has 45% forest, 6% urban, and 25% agricultural land covers while the urbanized Pensacola Bay watershed in northwestern Florida has approximately 20% urban, 39% forest, and 0.1% agriculture land covers (Fig. 1). The Lower Suwannee watershed consists of 63 sub-watersheds in an area of 408,828 ha. and is one of five watersheds that comprise the Suwannee River watershed (Katz et al., 1997). The Suwannee river is the second largest river in Florida in terms of average discharge (Light et al., 2002). The Pensacola Bay watershed comprises 15 sub-watersheds in an area of 140,825 ha. and is part of the Pensacola Bay system that is composed by five watersheds (Schwenning et al., 2007). As previously explained, the two