EFFECT OF URBANIZATION AND HURRICANES ON THE PROVISION OF ECOSYSTEM SERVICES IN THE LOWER SUWANNEE RIVER AND PENSACOLA BAY WATERSHEDS, FLORIDA, USA

By

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To my father and my mother

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Ecosystems can be impacted by different drivers that can alter their functionality. Thus, to understand the magnitude of these impacts to Ecosystem Service (ES) provision, quantification of ES and the drivers is important. This study estimated the effects of urbanization and hurricanes as direct drivers of carbon storage and timber volume, as well as water yield in forest areas in the Lower Suwannee River and Pensacola Bay watersheds, in Florida, USA. A current 2003 to 2060 urbanization scenario using spatial data and modeling, analyzed the effects of urbanization on ES. Results showed statistically significant differences at 95% confidence level between 2003 and 2060 in terms of provision of the three ES analyzed. For the hurricane analysis, this study estimated the potential loss of aboveground carbon storage and timber volume in high and low forest damage risk zones. Five factors were used in a decision tree to determine potential for forest damage due to hurricanes. Results showed that in the Lower Suwannee, 31% of the total aboveground carbon and 15% of the total timber were located in the high forest damage risk (HD) zone while the Pensacola Bay, had 0.5% of the total aboveground carbon and about the 0.7% of the

total timber in the HD zone. Knowledge on how different drivers impact ecosystems and their services will provide a better understanding to landowners, policy makers, about the consequences of land use change and natural disturbance on the benefits provided by forests.

CHAPTER 1
INTRODUCTION

Conceptualizing Ecosystem Services

Ecosystem services is becoming a mainstream concept in natural resources and environmental planning and management (Boyd and Banzhaf, 2007; Brown et al., 2007; de Groot et al., 2010; Farley and Costanza, 2010). The concept of ecosystem services has been increasingly used in the late 1990s (Costanza et al., 1997; Daily, 1997). There are several definitions of ecosystem services. One of the first uses of the term “ecosystem services” (ES), is by Daily (1997) who defined them as the natural ecosystem’s processes that can sustain and benefit human life. These ecosystem services provide biodiversity and ecosystem goods, such as food, timber, fuel wood, among others. In addition to the production of goods, ES are based on ecological functions, such as providing clean water, and aesthetic and cultural benefits.

Unfortunately, a coherent and integrated approach to practical applications of the concept in ecosystem and landscape planning, management and decision-making is lacking (Daily et al., 2009; de Groot et al., 2010; ICSU et al., 2008). Daily et al. (2009) mentioned that finding a link between decisions and ecosystems is a huge challenge. De Groot et al. (2010) discussed some alternatives to integrate ecosystem services and values in planning, policy and decision making. One example is the communication about ecosystem services and their values in a clear way with the objective of making the concept accessible to policy makers (de Groot et al., 2010). Another alternative is to make databases related to ecosystem services accessible to land use planners (de Groot et al., 2010).

Brown et al. (2007) refers to Daily (1997) and makes a distinction between ecosystem services and goods, and that both can produce benefits to human well-being. Ecologists are likely to distinguish between ecosystem goods and services (Brown et al., 2007; Daily, 1997; de Groot et al., 2010; European Commission, 2009), however others are often combining both as ecosystem services and referring to ecosystem goods as one category of ecosystem services named provisioning ecosystem services (Costanza et al., 1997; de Groot et al., 2010; Millennium Ecosystem Assessment, 2003). The concept of ecosystem services and goods are usually used as synonymous with ecosystem functions or processes. However, ecosystem processes determine ecosystem services and goods. Therefore, ecosystem processes are an intermediate step, thus they often do not produce direct benefits to people; however, they are necessary for human life and their values are included in the final values (Figure 1-1) (Brown et al., 2007; Costanza et al., 1997; de Groot et al., 2010; Millennium Ecosystem Assessment, 2003).

The most commonly cited concept for ecosystem services is the one developed by the Millennium Ecosystem Assessment (2003), and is based on a combination of the definitions of Daily (1997) and Costanza et al. (1997). According to the Millennium Ecosystem Assessment (2003), ES are the services provided by ecosystems with a direct influence on human well-being. There are different categories of ecosystem services according to the Millennium Ecosystem Assessment (2003), these include provisioning, regulating, cultural, and supporting services (Table 1-1). Provisioning services are the products people can get from the ecosystem; these are the ecosystem goods (e.g. food and timber). Regulating services refer to the benefits people receive from the regulation of ecosystem processes (e.g. flooding regulation and clean air). Cultural services are the nonmaterial benefits obtained from ecosystems (e.g. spiritual enrichment and recreation). Supporting services are those necessary for the production of other ecosystem services (e.g. primary production).

Natural ecosystems (e.g. forests, savannas, and prairies) and human-modified ecosystems (e.g. croplands and urban areas) should also be considered when assessing ecosystem services (Costanza et al., 1997; Millennium Ecosystem Assessment, 2003). Also, the four previously mentioned categories should be analyzed in order to have a more integrative approach because ecosystems can produce services in several categories. In doing so, ecosystems generate benefits to humans; some ecosystems provide more services than others. For example, forests provide a variety of services (Nasi et al., 2002; Yonavjak et al., 2011) in different categories: provisioning such as timber, pulpwood for paper, and non-timber forest products; regulating such as climate, erosion, and water flow control, as well as, cultural services such as recreation and tourism, and some supporting services such as nutrient and water cycling, and primary production (Table 1-1).

Specifically, southern United States (U.S.) forests are one of the most biologically diverse temperate forests in the world and consequently they produce a bundle of ecosystem services (i.e. a set of ecosystem services that are provided together as 'co-benefits' to people) (Raudsepp-Hearne et al., 2010). Therefore, people can get multiple ecosystem services; however they can decide which services are more relevant for them depending of what specific benefit they want from these ecosystems. For example, if a population wants to increase flood protection, or meet needs for supply of water, or an increase in small farm production, different services will be considered (McKenzie et al., 2011). So, the inclusion of the population in the process of knowing about what ecosystem services is important for them and their region is key. Additionally, these ecosystem services can be identified at different scales, such as local (e.g. timber), regional (e.g. clean water), and global (e.g. climate regulation) (Yonavjak et al., 2011), so this distinction in terms of scale is important for management purposes.

Although the fact that ecosystems provide services to people is already known, yet there are still several information gaps about ecosystem service dynamics, specifically how the provision of ecosystem services will change with changes in ecosystems (de Groot et al., 2010). Some aspects are still being studied, and especially those related to the interactions between ecosystem services (i.e. tradeoffs) and the effects of land cover change on the provision of these ES. As a result of this lack of information, some land covers that are multifunctional (and consequently multiple ES provision) are converted often to single-functional land covers (e.g. croplands). All ecosystems constantly change over time, and many of these changes are due to human impacts (e.g. urbanization) and natural processes (e.g. wildfire) (ICSU et al., 2008; Millennium Ecosystem Assessment, 2003). Therefore, understanding the causes of these changes, or drivers, is fundamental to minimize their impact on the provisioning of ecosystem services (Millennium Ecosystem Assessment, 2003).

By definition, drivers are ecological or human factors that can affect ecosystem composition, functioning, and processes, that then result in increasing or decreasing provisioning of ecosystem services (Millennium Ecosystem Assessment, 2003). These drivers can be classified as direct or indirect drivers. Direct drivers refer to those that directly affect ecosystem processes; on the other hand, indirect drivers are those affecting direct drivers. Examples of direct drivers are: land use change (e.g. forest to agriculture conversions), climate change, hurricanes, pest and diseases, among others. Indirect drivers can include: population growth, land use policies, land values, and market values for provisioning services (ICSU et al., 2008; Millennium Ecosystem Assessment, 2003; Yonavjak et al., 2011). One of the challenges about ecosystem services is the identification of the main drivers of change, in other words, the drivers that affect specific ecosystems, as well as their consequences on the provision of ecosystem services (Millennium Ecosystem Assessment, 2003). The definition of the key drivers for specific ecosystems will depend on several factors, such as historical information. For example, the most important direct drivers of change in terrestrial ecosystems over the past 50 years have been: land cover change (e.g. deforestation, cropland conversion) (Nelson, 2005) and the type of ecosystem (e.g. terrestrial and marine in that the main driver for marine ecosystems has been fishing). There are also some regional differences that determine the key driver's ecosystem, such as economic, institutional, technological, cultural, and demographic factors.

Effect of Drivers on the Provision of Ecosystem Services

In general, human beings modify ecosystems to increase the productivity of provisioning services such as food, timber, without paying attention to the tradeoffs, but increasing the use of one ecosystem service is resulting in a decrease in the use of another ecosystem service (Hancock, 2010; Millennium Ecosystem Assessment, 2003; Rodriguez et al., 2006). To better understand the influence of drivers in the form of land cover changes (e.g. forest to urban areas) and their effect on the provision of ecosystem services, it is becoming important to link this as a direct consequence to human wellbeing (ICSU et al., 2008), since human activities are producing changes in ecosystems rapidly (Metzger et al., 2006). The Millennium Ecosystem Assessment (2003) for example proposes a multi-sectorial approach for evaluating changes in different ecosystem services (e.g. crop production versus water quality), as well as to better understand the interactions between them and the impacts on people.

The future of ecosystems to provide ecosystem services will depend on socio-economic, climate, and land use changes among others drivers (Metzger et al., 2006). Various studies have been done to quantify the impact of land cover changes on the provision of ecosystem services. Reyers et al. (2008) found that ecosystem services experienced a decline ranging from 18%-44% as consequence of the land use change, specifically to croplands and urban areas in the Little Karoo in South Africa. Zang et al. (2011) quantified the decrease in ecosystem service values due to land use changes (urbanization and croplands) in the HaDaQi industrial corridor in China, and they found a decrease of 29% from 1990 to 2005. McNulty (2002) found that a single hurricane can affect carbon sequestration in forests converting 10% of the total carbon sequestered by U.S forests into dead biomass. According to Zhang and Nagubadi (2005), urbanization has a negative impact on timberland use in general. However, there is still a need to do more ecosystem service studies to assess the effects of land cover changes with more effective and simple methods.

Using Geographic Information Systems in Ecosystem Service Assessments

Most of the works that quantify value and analyze trade-offs among ecosystem services and land cover changes are based on Geographic Information Systems (GIS) methods. Since ecosystem services and land cover changes can be quantified and mapped using GIS (Boyd and Banzhaf, 2007; Metzger et al., 2006), this method is becoming widely used because its simplicity for studies involved in evaluating and mapping ecosystem services (Chen et al., 2009; Egoh et al., 2008; Troy and Wilson, 2006). Increasing interest in ecosystem services has derived the development of new tools to perform a multi-ecosystem service assessments (Waage et al., 2008). Some examples are presented by Waage et al. (2008) and include: (1) Artificial Intelligence for Ecosystem Services-ARIES, (2) Ecosystem Services Review-ESR, (3) Integrated Valuation of Ecosystem Services and Tradeoffs-InVEST, Multi-scale Integrated Models of Ecosystem Services- MIMES, and (5) Natural Value Initiative-NVI (Table 1-2).

Models such as InVEST use spatial data to estimate and map the quantity of ES (Tallis et al., 2011). The InVEST model is a GIS spatially explicit tool used for quantifying and valuing ecosystem services based on ecological production functions and economic valuation methods (Nelson et al., 2009; Tallis et al., 2011).The InVEST model is characterized by its repeatability and simplicity and because not much data is needed for running it; therefore it can be used in areas with poor data availability, and adjusted to the needs of the research because scenario analyses can be done (Tallis et al., 2011; Waage et al., 2008).

Even though GIS tools can help in the assessment of ecosystem services, a combination of GIS and field data is recommended to improve accuracy in most analyses (Zheng et al., 2012). Therefore, the U.S. Department of Agriculture (USDA) Forest Service Inventory and Analysis (FIA) program data can be used for this type of analysis of some ecosystem services. The FIA data set contains database for the forest lands in all the U.S States including forest characteristics, such as extent, condition, and volume. Several studies (Jenkins et al., 2003; Smith et al., 2004; Woodbury et al., 2007) have used this database for calculating forest carbon stocks, for example.

Objectives

Given the above, this study aims to identify and quantify the effects of ecosystem service drivers on land use and land cover change and the provision of ecosystem services in undeveloped areas in two watersheds located in the State of Florida, the Lower Suwannee River and the Pensacola Bay watershed. To determine the effects of land cover change, two direct drivers were analyzed: urbanization and hurricanes, which constitute threats to the state of Florida's ecosystems (Leatherman and Defraene, 2006; Wear, 2002a). Urbanization through conversion of natural ecosystems (Millennium Ecosystem Assessment, 2003), has been a key driver in the State, as a result of population growth, and because new urban areas are needed to allocate this new population. In Florida, according to Zwick & Carr (2006) between 2006 and 2060 the population of the State is projected to double. The second driver that will be analyzed are hurricanes, since according to several authors, one of the main consequences of climate change in Florida will be the increase of hurricane's intensity and frequency (Florida Oceans and Coastal Council, 2009; Stanton and Ackerman, 2007). Therefore, the importance of understanding the possible consequences of these two drivers on the provision of forest ecosystem services is becoming crucial.

The following chapters addressed the two drivers previously mentioned: urbanization and hurricanes in two watersheds in the state of Florida, the Lower Suwannee River and the Pensacola Bay located in the Northeastern and Northwestern Florida respectively. The 2nd chapter analyzed the effects of urbanization on the provision of ecosystem services specifically carbon storage, timber volume and water yield by using the GIS spatial model InVEST to quantify the ecosystem services in a 2003-land cover and then compared it to a 2060-population distribution scenario (Zwick and Carr, 2006). The hypothesis and objectives were:

- Hypothesis: Urbanization directly affects carbon storage, timber volume, and water yield. Carbon storage and timber volume are negatively correlated with urbanization and water yield is positively correlated.
- Objective 1: Determine the effects of Land Use and Land Cover changes in undeveloped areas due to urbanization on the provision of ecosystem services such as carbon storage, timber volume, and water yield in the two watersheds before mentioned.
- Objective 2: For the years 2003 and 2060, to estimate the amount of carbon storage, timber volume, and water yield in the two watersheds based on the InVEST model and the U.S.D.A Forest Inventory Data.

The 3rd chapter used a decision tree to develop a framework to identify the risk of forest damage due to hurricanes and determined the potential loss of aboveground carbon storage and timber volume in high and low forest damage risk zones. The map was developed based on information from previous studies (McNulty, 2002; Oswalt and Oswalt, 2008; Stanturf et al., 2007) that determined the main forest structure factors that increase the risk of hurricane damage to forests. The objectives were:

- Objective 1: Develop a hurricane framework based on a decision-tree analysis, to identify high and low forest damage risk zones due to hurricanes based on the tree diameter and height, species type (e.g. softwoods and hardwoods), and distance to landfall.
- Objective 2: Assess and map the potential loss of aboveground carbon storage and timber volume due to hurricanes in the two watersheds previously mentioned, based on the InVEST model and the U.S.D.A Forest Inventory Data in the high and low forest damage risk zones due to hurricanes.

Finally, the 4th chapter presented general conclusions including an analysis of the two drivers and their effects on ecosystem services, as well as alternatives to better include ecosystem services in decision-making.

Table 1-1. Categories of ecosystem services. [Adapted from Millennium Ecosystem Assessment. 2003. Ecosystems and Human Well-being: A Framework for Assessment (Page 5, Figure 1). Island Press, Washington.]

Categories	Definition	Examples
Provisioning services	Products obtained from ecosystems	Food, fresh water, fuel wood. Fiber. Biochemical, genetic resources
Regulating services	Benefits obtained from regulation of ecosystem processes	Climate regulation, disease regulation, water regulation, water purification, pollination
Cultural services	Non-material benefits obtained from ecosystems	Spiritual and religious, recreation and ecotourism, aesthetic, inspirational, educational, sense of place, cultural heritage
Supporting services	Services for the production of all other ecosystem services	Soil formation, nutrient cycling, primary production

Table 1-2. Multiple Ecosystem Services assessment tools. [Adapted from Waage, S., Stewart, E., and K. Armstrong. 2008. Measuring Corporate Impact on Ecosystems: A Comprehensive Review of New Tools: Synthesis Report. Business for Social Responsibility, San Francisco, CA.]

Model name	Description	Developer	Type of results
Artificial Intelligence for Ecosystem Services (ARIES)	A computer model uses for estimating and forecasting ecosystem services provision and economic values in a specific area	University of Vermont's Ecoinformatics "Collaboratory" Conservation International, Earth Economics, and experts at Wageningen University	Spatially explicit maps
Ecosystem Services Review (ESR)	A sequence of questions that helps managers develop strategies to manage risks and opportunities arising from a company's dependence on ecosystems	World Resources Institute (WRI), Meridian Institute, and World Business Council for Sustainable Development (WBCSD)	Risk and/or opportunity analysis

Table 1-2. Continued

Model name	Description	Developer	Type of results
Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)	A decision-making aid to assess how distinct scenarios may lead to different ecosystem services and human-well-being related outcomes in particular geographic areas	Natural Capital Project, a joint venture among Stanford University's Woods Institute for the Environment, The Nature Conservancy and World Wildlife Fund (WWF)	Spatially explicit maps
Multi-scale Integrated Models of Ecosystem Services (MIMES)	A multi-scale, integrated suite of models that assess the true value of ecosystem services, their linkages to human welfare, and how their function and value may change under various management scenarios	University of Vermont's Gund Institute for Ecological Economics	Spatially explicit maps
Natural Value Initiative (NVI)	An evaluation benchmark methodology for assessing biodiversity and ecosystem services-related risks and opportunities in the food, beverage and tobacco sectors	Fauna & Flora International, Brazilian business school FGV, and the United Nations Environment Programme Finance Initiative	Risk and/or opportunity analysis

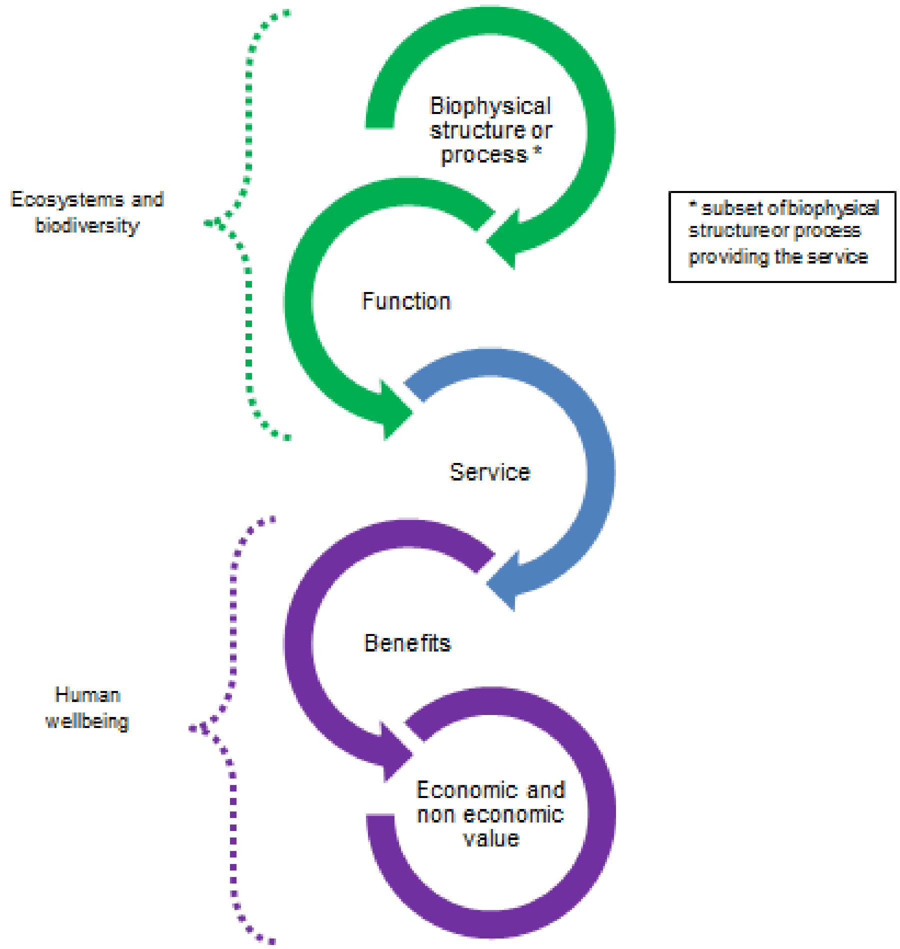


Figure 1-1. Framework for linking ecosystems to human wellbeing. [Adapted from de Groot, R.S., Alkemade, R., Braat, L., Hein, L., and L. Willemen. 2010. Challenges in Integrating the Concept of Ecosystem Services and Values in Landscape Planning, Management and Decision Making (Page 264, Figure 2). Ecological Complexity.]

CHAPTER 2
EFFECTS OF URBANIZATION ON THE PROVISION OF ECOSYTEM SERVICES

Background

Land cover change affects ecosystem structure, processes and functions, and consequently their capacity to deliver ecosystem services (Daily, 1997; European Commission, 2009; Metzger et al., 2006; Millennium Ecosystem Assessment, 2003; Su et al., 2012). The changes in land cover are increasingly important, as they are projected to increase and accelerate in the next decades due to human activities (IPCC, 2001; Vitousek et al., 1997; Wear and Greis, 2002a). However, analyzing different land cover change scenarios is not an easy task as land cover changes due to urbanization are determined by a variety of factors including socio-economic and climate factors, that can damage or modify natural ecosystems and determine their vulnerability to such changes (Metzger et al., 2006).

One of the major threats to ecosystems is human population growth. World population is rapidly increasing, and according to the U.S Department of Commerce, Census Bureau (2002) the population by 2050 is projected to be 9 billion. The result of this population rise will be more human influences on these ecosystem services such as food, timber, and clean water, as well as changes in land cover (European Commission, 2009; Millennium Ecosystem Assessment, 2003; Vitousek et al., 1997). So, land cover change, driven by urbanization as well as agricultural expansion, deforestation, over-exploitation of natural resources, and climate change (European Commission, 2009; Foley et al., 2005), have been identified as some of the most important drivers affecting terrestrial ecosystems (Reyers et al., 2009; Vitousek et al., 1997). Although, land cover change can contribute to economic development, it is normally accompanied by degradation of ecosystem services due to unsustainable human practices resulting in a reduction of the benefits for future generations (Millennium Ecosystem Assessment, 2003; Vitousek et al., 1997). The State of Florida is not an exception to this trend, according to Zwick & Carr (2006) the population will double by 2060.

Urbanization, defined as the development of new urban areas from non-urban lands, is one important human-induced disturbance that affects natural ecosystems (Bengston et al., 2005; Zhang et al., 2012). More specifically, urbanization can alter the structure, composition, processes and functions of the ecosystems, in doing so it can deplete ecosystem services' provision (Grimm et al., 2008; Xu et al., 2007).Urbanization is also predicted to alter significant areas of forest and other natural systems as well as agricultural areas in the next few years with forests being the most subject to fragmentations (Alig et al., 2004; Smail and Lewis, 2009; Wear and Greis, 2002a). According to Bengston et al. (2005), during the latter half of the 1990s there was an increased concern in unplanned urbanization, especially because of the resulting environmental impacts. This unplanned urbanization was identified as the most significant factor affecting forest ecosystems in the southern U. S. (Wear, 2002b), since 45% of Florida's forest area declined since 1992 (Wear and Greis, 2002a). Urbanization can alter both biotic and abiotic ecosystem properties (Grimm et al., 2008) and have significant impacts on a terrestrial ecosystem's carbon cycle (Xu et al., 2007), as well as other ecosystem services such as clean water by increasing point and non-point pollutants (Grimm et al., 2008; Wear and Greis, 2002a; Zheng et al., 2012).

Carbon Storage and Urbanization

It is estimated that urbanization has emitted about 0.21 Pg carbon between 1945 through 2007 in the Southern U. S. (Zhang et al., 2012). However, urban areas can also store carbon in planted and reforested trees and can reach the pre-urbanization amounts in 70-100 years (Zhang et al., 2012). According to Zheng et al. (2012), forest carbon sequestration can be reduced by 1.7-9.3% as a result of urbanization in the forested wildland-urban interface areas in New England, USA. They also mentioned that carbon sequestration can increase by 40% by 2030.

Carbon storage in ecosystems is of interest because of climate change mitigation policies (Davies et al., 2011). The Kyoto Protocol for example proposes to take carbon storage and sequestration as a valid mechanism for emission reduction to mitigate global climate change (Gorte, 2009; Newell and Stavins, 2000; Stavins, 1999). Forests are key for carbon storage and critical to the global carbon cycle as they comprise a large amount of carbon comparing to other terrestrial ecosystems (Gorte, 2009; Harmon, 2001; Jandl et al., 2007; Yonavjak et al., 2011). Of the total carbon stored in terrestrial vegetation and soils (2,200 Giga tons-Gt), forests comprise over half (53%) of this value (Braatz, 2001). Gorte (2009) presented a comparison of carbon stocks for different land covers and the highest value corresponded to forests ranging from 68-182 tons per acre and the lowest to croplands with 37 tons per acre.

In forests, carbon can be stored in different "pools", such as in the: soil, live tree, standing dead tree, forest floor, down dead wood, and understory vegetation (Harmon, 2001; Smith et al., 2004; Tawil, 2007). However, in some cases, only forest and forest products are considered relevant carbon pools (Harmon, 2001). Southern forests represent 29% of the U.S. forests and play an important role in the sequestration of carbon at a global scale. Approximately one-third of the carbon sequestered in U.S. forests corresponds to Southern forests, hence they can help in mitigating the effect of climate change (Hanson et al., 2010; Wear and Greis, 2002a).Therefore, when forests are degraded or their area reduced, the carbon stored is directly affected (Hanson et al., 2010) and when forests are degraded or converted; the carbon stored is directly affected (Hanson et al., 2010).

Timber and Urbanization

Timber products are considered provisioning ecosystem service and are used to meet a variety of needs (Millennium Ecosystem Assessment, 2005). To consider timber as a provisioning ecosystem service, it should provide direct benefits to people (e.g. wood for furniture or fuel) (Millennium Ecosystem Assessment, 2005), and hence should be expressed in terms of production. The benefits of this ecosystem service are widely recognized and are more easily valued than other ecosystem services because market prices exist for timber and non-timber forest products (de Groot et al., 2010). US Southern forests have an important potential for timber production (Prestemon and Abt, 2002a). The South produces more than 60% of the timber products in the U.S. (Prestemon and Abt, 2002a) and according to Bystriakova et al. (2005), timber harvest at the global scale has been increased by 60% in the last four decades and the trend is to continue increasing but at a slower rate. Zhang & Nagubadi (2005) found that urbanization is one the drivers generating the decline in timberland area. Cubbage et al. (1995) also found that urbanization reduced the timber supply especially that of softwoods. Additionally Hodges et al. (1998) found that in St. Tammany Parish in Louisiana, forests were reduced by urban development.

Water Yield and Urbanization

Water is another important resource that provides services to human. Water enters ecosystems through precipitation and leaves through evaporation and runoff

(Chapin III et al., 2002). Precipitation can be affected in different ways in terrestrial ecosystems. It can be: (1) intercepted by vegetation, (2) stored in the soils where it can be taken up by vegetation roots or discharged into the aquifer and surface streams, (3) evaporated by soil and (4) transpired by vegetation. As water moves through the land, human activities and land use/cover types determine its physical and biochemical characteristics (Conte et al., 2011). Land use changes can alter water quantity and quality (Foley et al., 2005; Sun et al., 2005). Therefore, determining the effect of land use/cover on water yield and quality becomes important. Water yield, defined in this study as all annual precipitation that does not evaporate from soil and water or transpires from vegetation (Mendoza et al., 2011).

Forests can reduce runoff, as a result of increased evapotranspiration and infiltration, as well as improve water quality and maintain stream levels thus minimizing stormwater runoff (Hanson et al., 2010; Nasi et al., 2002). Several studies have determined the relationship between water and forests (Bosch and Hewlett, 1982; Sun et al., 2005) and urban areas. For example, water flow can change after urbanization since Hollis (1977) found that the median flow was increased 0.057 m^3 to 0.142 m^3 per second in the Canon’s Brook catchment in England. Arnold et al. (1987) also analyzed the impact of urbanization on water yield in a Dallas, Texas, USA watershed, and found that it changed from rural to about 77 percent urban. Based on a model called Simulator of Water Resources in Rural Basins (SWRRB) they also calculated that annual surface runoff with no increase in urbanized area would be 135 mm rather than 151 mm, about 10% increase. Boggs and Sun (2011) compared two areas in North Carolina, one more urbanized and the other more forested, and concluded that urbanization can increase annual discharge volumes due to the decrease in evapotranspiration. Some studies were done in Florida, where Sun et al. (2008) found that land use and land cover changes will have little effect on water quantity and the water demand relationship in 2020 in the southeastern U.S. They also mentioned that land use changes affects water yield and evapotranspiration loss. Many studies in Florida have analyzed the effect of urbanization on water quality (Cooley and Martin, 1979; Frick, 1998), and other consequences on water such as impact on insect communities (Jones and Clark, 1987) and water supply (Boggess, 1968). However more information about the impact of urbanization on water yield is lacking in the State of Florida.

Ecosystem Services Models

The previously mentioned ecosystem services can be quantified and mapped using Geographic Information Systems (GIS) models (Boyd and Banzhaf, 2007; Metzger et al., 2006). Models such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) use spatial data to estimate and map the quantity of ES (Tallis et al., 2011). The InVEST model is a GIS spatially explicit tool used for quantifying and valuating ecosystem services based on ecological production functions and economic valuation methods (Nelson et al., 2009; Tallis et al., 2011). The model can determine the quantity of ecosystem services in a current land use/cover and how these ecosystem services can change in the future with different scenarios such as new policies, and programs. Model outputs are in biophysical terms (e.g. tons of carbon stored) or economic terms (e.g. net present value of carbon sequestered) (Tallis et al., 2011).

In this chapter, three ecosystem services were analyzed: two regulating services, (1) carbon storage as an indicator of climate regulation and (2) water yield as an indicator of flooding regulation, as well as one provisioning service, (3) timber volume, as an indicator of timber production. The objectives were to determine the effects of urbanization on these three ecosystem services (carbon storage, timber volume, and water yield) in the Lower Suwannee River and Pensacola Bay watersheds in Northwestern Florida, respectively. This specific study aim was to quantify three key ES in a current and a modeled urbanized scenario using the InVEST model, the U.S. Department of Agriculture (USDA) Forest Inventory and Analysis (FIA) field data, and an urbanization land cover map for 2060 using the population distribution map produced by the GeoPlan Center at the University of Florida. The hypothesis tested was that urbanization directly affects carbon storage, timber volume, and water yield; carbon storage and timber volume are negatively correlated with urbanization and water yield is positively correlated. This quantification of ecosystem services can then contribute to the valuation of ecosystems, as well as to understanding the magnitude of urban development on ES in subtropical Florida, thus promoting better understanding by landowners, urban planners and policy makers and for better assessments of ES values.

Methods

Study Areas

The Lower Suwannee River and the Pensacola Bay watersheds in the State of Florida were selected for this study. The Lower Suwannee River watershed is located in Northeastern Florida and the Pensacola Bay in Northwestern Florida (Figure 2-1). These two watersheds are different in terms of land use/cover characteristics with the Lower Suwannee River watershed being more forested and the Pensacola Bay being more urbanized (Table 2-1).

The Lower Suwannee watershed consists of an area of 408,828 ha, and is one of five watersheds that comprise the Suwannee River watershed (Katz et al., 1997). The Lower Suwannee watershed is roughly centered at 29° 51’ 34” North and 83° 0’ 22” West and eight counties are within the watershed boundary: Columbia, Dixie, Gilchrist, Lafayette, Levy, Madison, Suwannee, and Taylor. This watershed was chosen for the analysis due to its hydrological nature as it comprises much of the Upper Floridian aquifer springs and the highest concentration in the world of first magnitude springs (Obreza and Means, 2006). The Suwannee River is the second largest river in Florida in terms of average discharge (Light et al., 2002). Several studies have been done in the Lower Suwannee, because in the past years the main threat to this area is the transition from natural ecosystems to more intense land-use practices (Martin, 2007). This area is defined by Obreza & Means (2006) as an area with unique biota and water resources that need to be protected.

The Suwannee watershed area is characterized by the presence of karst features, wetlands, lowland topography, and a small number of tributary streams (Katz et al., 1997). Interactions between groundwater and surface water occur within the Suwannee River watershed due to the presence of karst features. Five different ecological subsections are within its boundaries: 232Jf, 232Bj, 232Ka, 232Lc, and 232Db (Table 2-2). The land cover type in the watershed is predominantly forest, agriculture, and wetlands (Katz et al., 1997). The Lower Suwannee River watershed is divided into 63 sub-watersheds. The watershed has subtropical climate with warm summers and moderate winters (Katz et al., 1997). The average precipitation in the watershed is 1,270 mm per year (Obreza and Means, 2006).

The Pensacola Bay watershed comprises an area of 140,825 ha and is part of the Pensacola Bay system that is composed by five watersheds(Schwenning et al., 2007). The watershed is roughly centered at 30° 25' 43" North and 86° 59' 29" West. The counties of Escambia, Okaloosa, and Santa Rosa are within the watershed boundaries. This watershed includes the Pensacola Bay estuary and parts of four major rivers: Escambia, Blackwater, Shoal and Yellow Rivers, and some small tributaries (Florida Department of Environmental Protection, 2007; Thorpe et al., 1997). The watershed was chosen because of its difference land cover characteristics compared to the Lower Suwannee River watershed. The Pensacola Bay watershed is more urbanized than the Lower Suwannee with around 30% of its area covered by urban areas. Three different ecological subsections are within its boundaries: 232Bj, 232Bg, and 232Lb (Table 2-2). The Pensacola Bay system has unique features such as its morphology and the hydrodynamics that are considered key points for the natural ecosystems (Hays, 2009). However, over the last decades it was impacted by human activities such as habitat alteration, urban development, and point and non-point source pollution (Thorpe et al., 1997) such as industrial and domestic waste and non-point sources from urban, suburban, and agricultural areas (Thorpe et al., 1997; U.S. Environmental Protection Agency, 2004).

The most pollution in the watershed occurs around urban areas (Thorpe et al., 1997). Natural ecosystems such as wetlands and aquatic habitats have been affected by deposition and sedimentation (Thorpe et al., 1997), as well as through conversion and fragmentation (Northwest Florida Water Management District, 2006). Another threat to the watershed are hurricanes, which occur approximately every 5 to 10 years (NOAA-

National Hurricane Center, 2012a). The Pensacola Bay watershed has humid subtropical weather with warm temperatures. The annual precipitation ranges from 730 to 2,280 mm (Hays, 2009) with an average of 1,625 mm (Thorpe et al., 1997).

Quantification of Ecosystem Services

Carbon storage

Carbon storage was analyzed using two data sets: the USDA Forest Inventory and Analysis (FIA) data and the Florida Vegetation and Land Cover 2003 (Florida Fish and Wildlife Conservation Commission, 2004) in addition to modeled urbanized land cover for the year 2060 (Zwick and Carr, 2006). Zheng et al. (2012) mentioned that the combination of field data (e.g. FIA) and remote sensing products (e.g. land cover maps) are necessary to improve carbon estimations accuracy. The InVEST model, developed for the Natural Capital Project (Natural Capital Project, 2011), was used for analyzing the amount of carbon storage in the 2003-land cover and the 2060-urbanized land cover. These datasets were used as input data for the model, which estimates carbon storage in Mega grams (Mg) per hectare (ha) for each land cover.

Forest Inventory and Analysis Program data

The U.S. Department of Agriculture (USDA) Forest Service Inventory and Analysis (FIA) program data was used for analyzing forest carbon storage. The FIA characterizes forest lands in all the U.S States including forest data and characteristics, such as extent, condition, and volume. The FIA Program started in 1929 with periodic forest inventories of nation-wide network of plots in all U.S. States. Since 1999, those inventories are conducted annually (Jenkins et al., 2003; Woudenberg et al., 2010). The plot-level information is based on the individual tree measurement.

One limitation with the FIA data is that exact geographic coordinates (latitude and longitude) of the plots are not provided because of the “Privacy provision” enacted by Congress in the Food Security Act of 1985 to ensure private landowners’ privacy and plot integrity. However, the location of the plots is within a buffer of approximately 1 mile or ½ mile from their true position. Moreover, 20% of the plots are swapped, which means that some private plots are exchanged with other similar private plot in the same county (Woudenberg et al., 2010). This situation creates an uncertainty when plots need to be overlaid with other GIS data. Sabor et al. (2007) found that the potential error of using the altered location of the plots in combination with other layers, for example for a 30 meters by 30 meter raster layer, results in plot misclassification that ranged from 32% to 66%. However, different approaches, based on other FIA attributes, can be applied to better approximate true plot location. For example, only the 1-10 % of plots are misclassified when analyzing for ecological subsection data (Sabor et al., 2007). As such, including the ecological subsection strata, FIA survey unit and County attributes can better help specify the true location of plots. For example in the case of county, only the plots located within a specific county can be extracted from the FIA database (i.e. Tree table or Condition table).

Carbon pools analysis

As mentioned before, carbon storage analyses were performed based on the different forest types according to the 2003 Florida Vegetation and Land cover map produced by the Florida Fish and Wildlife Conservation Commission (Florida Fish and Wildlife Conservation Commission, 2004). This map was developed based on Landsat Enhanced Thematic Mapper satellite imagery with a 30 meter spatial resolution and detailed distinction between different ecosystems. It contains 43 classes of vegetation and land cover, 26 being natural and semi-natural vegetation types, 16 types of disturbed lands (e.g., agriculture and urban), and a single water class (Stys et al., 2004). For the carbon pool analysis, 11 forest cover classes were analyzed. The classes are shown in Table 2-1, as well as the presence or absence in each watershed.

To deal with the problem of the true FIA plot location, a different approach was developed to try to approximate the carbon values for the different types of forests. Some attributes available at the FIA database were considered, specifically the FIA Survey Unit, ecological subsection, county, condition status, and stand age (Figure 2-2). The description of each attribute is shown in Table 2-3. The original 11vegetation classes in the map were reclassified using ArcGIS® Spatial Analyst (ESRI, 2011a) to add new values to the raster file. New classes were created using the FIA attributes: Ecological subsection (U.S.D.A Forest Service, ECOMAP Team, 2007) and County. Both vector files were converted to raster format and combined using ArcGIS® Spatial Analyst. The result was one raster file showing the unique combination of classes for each forest ecosystem, ecological subsection and county (Figure 2-3). Once forest ecosystems were identified for each watershed, the main forest tree species for each of them were identified based on vegetation descriptions prepared by Gilbert and Stys (2004) that contains the list of forest tree species observed in each forest ecosystem. Then, the forest tree species found in the FIA database were considered and the species codes were identified (Table 2-4).

The four carbon pools, measured in metric tons per hectare, were aboveground biomass, belowground biomass, soil organic matter and dead biomass (Tallis et al., 2011). Carbon aboveground biomass refers to all living materials above the soil (e.g.

bark, leaves, trunks), belowground biomass corresponds to the living root systems of the aboveground biomass, soil organic matter comprises the organic component of the soil, and dead biomass includes the litter, and downed and standing dead wood (Tallis et al., 2011). Table 2-5 shows the FIA attributes used for each carbon pool calculation. The FIA data corresponding to cycle 8 (2002-2007) were used in the analysis as they correspond to the 2003 land cover classification. To extract the carbon aboveground and belowground from the FIA data, the Tree table was used (Woudenberg et al., 2010), which contained individual tree information. A tree expansion factor, which can be found in the Tpa_unadj attribute in the Tree table was used. The expansion factor was used to scale each tree on a plot to a per-acre basis, considering the number of trees per acre (TPA) (Woudenberg et al., 2010). Per tree values for aboveground and belowground carbon were multiplied by the corresponding Tpa_unadj to get the plot-level information in pounds per acre.

Using the Pivot table function in Microsoft Excel® (Microsoft, 2010), these values were summed by plot (PLT_CN) considering specie code (SPCD), FIA survey unit (UNITCD), ecological subsection (ECOSUBCD), county (COUNTYCD), condition status (COND_STATUS_CD), and stand age (STDAGE). The carbon value calculated was the total carbon aboveground and belowground for each plot. The total values were converted to tons per hectare then; the average was calculated using these plot values to get the value for each species, considering the ecological subsection and county. Only plots with the condition status defined as “forest land” and with a stand age ranging from 1 to 72 years were considered in the analysis. Based on a previous study where the exact locations of the FIA plots were obtained for the Forest Stewardship

Properties located in the State of Florida (Abd-Elrahman et al., 2012), the range of stand ages were extracted. To assign the carbon values to a raster file (i.e. reclassified land cover) from the FIA plot locations, the forest type were identified in both datasets, so the carbon values in the FIA data for one specific forest type, one ecological subsection, and one county were assigned to the each forest ecosystem in the raster file that corresponded to the same attributes (i.e. ecological subsection and county). The final carbon above and belowground for each forest ecosystem was the result of the sum of all the species within that land cover type. No timber harvest effects were considered in the analysis.

For the downed dead, standing dead, soil, understory aboveground, understory belowground, and litter carbon the approach used was similar to the approach described above. Since these C values are in the FIA Condition table that provides plot-level information, the forest type attribute was used. The values for these carbon pools are by plot and presented in tons per acre, which were then converted to tons per hectare. Once all carbon values were calculated from the FIA data, the different values were aggregated into the four pools (Table 2-5). In table 2-6 the resulting carbon pool for the Pensacola Bay watershed are presented. The carbon pools for the urbanized 2060 scenario were estimated based on the assumption that the forest carbon pool in 2060 will be 5 percent less when compared to the pool in 2010 (Huggett et al., 2002). Several authors refer to the uncertainty in the forest carbon projections, so this 5% assumption was made (Heath and Smith, 2000; Huggett et al., 2002; Moore et al., 2002).

InVEST carbon storage model

The InVEST carbon storage model summed the amount of carbon stored in the four aforementioned pools based on the land cover map (Tallis et al., 2011). The carbon values were estimated for each pixel considering the previously mentioned land cover types. Model output is the total carbon storage, which sums the four pools. Intermediate results are the carbon aboveground, belowground, dead, and soil (Tallis et al., 2011). Model output is expressed in Mg of carbon per pixel units and then converted to Mg per hectare. A flow chart illustrating the carbon estimation approach is shown in Figure 2-4.

Timber volume

The approach used for analyzing timber production is similar to the one used for the carbon estimation. The timber volume and the timber in the sawlog portion were calculated and are basically the potential timber available for harvesting. Timber volume was processed using FIA survey unit, ecological subsection, and county. Only the condition status defined as forest land and the stand age ranging from 1 to 72 years were considered in the analysis. From the Tree table, two attributes were analyzed: the net volume (volnet) and the net volume in the saw-log portion (volsaw). These attributes contain tree-level information, so the expansion factor was used to convert to plot-level data in cubic feet per acre. The final results were converted to cubic meter per hectare and volume values were assigned to individual pixels in the map. Figure 2-4 presents the timber estimation process flow chart adopted in this study. For the timber volume projections for 2060, the volume values presented in Prestemon and Abt (2002b) based on the Subregional Timber Supply Model (SRTS) of Abt et al. (2000) were used. An average per-year increase in timber volume was used to determine the timber volume for the year 2060.

Water yield estimation

The InVEST water purification model estimates the annual average runoff (water yield) or the effect of land cover type on the annual water yield (Tallis et al., 2011). The model was used to estimate the water yield from each pixel in the form of precipitation minus the evapotranspiration fraction. The model sums the pixel water yield information to get the sub-watershed level value, and then the sub-watershed values are summed to get the watershed level value (Tallis et al., 2011). The model is for surface water and does not account for groundwater (Mendoza et al., 2011). However, there is no differentiation between surface, subsurface and baseflow water in the InVEST model (Tallis et al., 2011). According to Zektser and Loaiciga (1993), groundwater comprises on average 30% of the stream flow around the world and in some areas can reach up to 90% (Winter, 1999). Therefore, in areas where groundwater is influential, the InVEST model can produce low water yield values when compared to observed stream flow levels (Mendoza et al., 2011). Figure 2-5 shows the conceptual framework of the model.

This model is based on the Budyko curve and annual average precipitation (Tallis et al., 2011). The Budyko curve describes the relationship between precipitation and actual and potential evapotranspiration (Mendoza et al., 2011) . This approach for calculating the evapotranspiration depends on water availability (i.e. precipitation) and atmospheric demand (i.e. potential evapotranspiration (Mendoza et al., 2011; Zhang et al., 1999; Zhang et al., 2001). The annual water yield is estimated based on precipitation and actual evapotranspiration. The model analyzes each pixel considering each land cover; Equation 2-1 shows the calculation.

$$Y_{xj} = \sum_j \left(1 - \frac{AET_{xj}}{P_{xj}}\right) \cdot P_{xj} \cdot A_{xj} \tag{2-1}$$

where Y_{xj} is the annual water yield, AET_{xj} is the annual actual evapotranspiration on pixel x with LULC j and P_{xj} is the annual precipitation in pixel x with LULC j, and A_{xj} is the area of x in LULC j.

The evapotranspiration partition of the water balance is also calculated. This is an approximation of the Budyko curve presented by Zhang et al. (2001) who defined this equation by using potential evapotranspiration and plant available water content. The maximum difference in this ratio (AET/P) corresponds to forest cover areas, and in this case trees will use more soil water storage (Zhang et al., 2001) and is described as:

$$\frac{AET_{xj}}{P_{xj}} = \frac{1+w_{xj}\,R_{xj}}{1+w_{xj}\,R_{xj}+\frac{1}{R_{xj}}} \quad (2\text{-}2)$$

where R_{xj} is the ratio of potential evapotranspiration to precipitation, named the Budyko dryness ratio and w_{xj} is a modified dimensionless ratio of plant accessible water storage to expected precipitation during the year (Mendoza et al., 2011). Therefore, w_{xj} is given by Equation 2-3:

$$w_{xj} = Z\left(\frac{AWC_x}{P_{xj}}\right) \quad (2\text{-}3)$$

where AWC_x is the volumetric (mm) plant available water content, Z is the seasonality factor showing the rainfall distribution (Mendoza et al., 2011).Finally, the ratio of potential evapotranspiration to precipitation (R_{xj}) is calculated by

$$R_{xj} = \frac{k_j \cdot ETo_x}{P_{xj}} = \frac{PET_{xj}}{P_{xj}} \quad (2\text{-}4)$$

where ETo_x that is the reference evapotranspiration from pixel x and k_{xj} is the evapotranspiration coefficient associated with LULCj on pixel x.

Water model input data process

The input parameters for the InVEST water yield model are summarized in Table 2-7, as well as parameter descriptions, units of measure, and data sources. The process to get the data for each of the inputs needed for the water yield model is described in the next section, as well as the data source.

Precipitation. Annual precipitation data for the years 1998-2008, were obtained from the PRISM Climate Group (formerly SCAS) at Oregon State University and an average precipitation was calculated using the 10 year values. For the year 2060 precipitation data, the projections of Coulson et al. (2010) based on the Australian Commonwealth Scientific and Industrial Research Organization-CSIRO Mk3 Climate System, were used. The CSIRO Mk3 climate model is a representation of the components of the climate system: atmosphere, land surface, oceans, and sea-ice with the main objective of investigating the climate system to be able to develop predictions (Gordon, 2002). Average values for the years 2055-2065 were used.

Soil depth. The source data was the U.S. General Soil Map (State Soil Geographic-Statsgo2) developed by the USDA Natural Resources Conservation Service. The Soil Data Viewer[1] tool was used to produce the soil thematic maps. The tool generated spatial information directly in a vector format that was converted to raster format for use in the model. The maximum soil depth and water table depth were generated using this tool and the final input is the combination of these two data sets.

Average annual potential evapotranspiration (PET). The original data (organized by county in an ASCII format with 2 km spatial resolution) was obtained from

[1] Soil Data Viewer is a tool built as an extension to ArcMap that allows a user to create soil-based thematic maps

U. S. Geological Survey's Florida Integrated Science Center (U.S.Geological Survey, Florida Water Science Center, 2008) and converted to raster format. Preparing the PET data involved the following steps: (a) getting the annual data for each cell (original data is daily) for the years 1998-2008, (b) converting tabular data to spatial data using the latitude and longitude coordinates of each data point, and (c) converting point data to a raster format using the Inverse Distance Weighting (IDW) interpolation method. The IDW interpolation used a weight to determine cell values, this weight is a function of inverse distance, and so closer data points exert more influence than farther data points (ESRI, 2012a). The annual raster layers were averaged to get the average annual potential evaporation layer. For the 2060 PET, the projections of Coulson et al. (2010) based on the CSIRO model were used. An average value for the years 2055-2065 was used.

Plant available water content. The InVEST model requires a GIS raster dataset with a plant available water content value for each cell. The source data is the General Soil Map-STATSGO2 obtained from the USDA-NRCS. The Soil Data Viewer tool was used to get the vector data set, which was converted to raster format and used in the model.

Maximum root depth. Values for vegetated land cover types, except for wetlands and grasslands species were collected from Canadell et al. (1996). To assign maximum root depth values to each land use/land cover type the main species for each land cover were identified. For the non-vegetative land use/land cover classes such as, urban, extractive and Sand/Beach, a value of 1 was assigned as suggested by Tallis et al. (2011).

Zhang constant. This is a factor used to characterize the seasonality of precipitation in an area (Tallis et al., 2011). The Lower Suwannee River and Pensacola Bay watersheds are located in a subtropical ecoregion, where most rainfall occurs during the summer months similar to tropical ecoregions. According to Tallis et al. (2011), the value for tropical or sub-tropical watersheds was 4; hence this value was used.

Evapotranspiration coefficient. This coefficient is needed when the reference evapotranspiration is used in the model; however if the PET is used, this coefficient is not required (Eq. 2.4), thus a value of 1 was assigned to all land cover types.

InVEST water model assessment

An assessment of the water yield model was done based on the comparison of the average annual water yield from the model and the average annual streamflow data from the Gopher River gage station (Site 02323592) located at a downstream point in the watershed. A 10 year average value should be used for the stream flow data (Tallis et al., 2011). However, the streamflow data found at the U.S. Geological Service (USGS) National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis/), had information for the period 2000 to 2008. NWIS has information about the stream discharge for 8 sites along the Suwannee River (Nielsen and Norris, 2007). The assessment was done only for the Lower Suwannee River watershed.

2060 land use and land cover map

The 2060 urbanization scenario -land use and land cover map was developed based on the 2003-Florida Vegetation and Land Use map and the 2060-Florida population distribution scenario (Zwick and Carr, 2006). The population distribution map for 2060 is based on the population projections from the Bureau of Economic and

Business Research (BEBR) and GIS suitability analysis (Zwick and Carr, 2006). Based on population projections, the amount of people that need to be allocated can be identified, as well as the land area in hectares.

The Florida 2060 map was developed by combining spatial data to model land-use suitability considering conservation (forest), urban and agricultural lands. Three main concepts were considered in the analysis: suitability, preference, and conflict mapping (Carr and Zwick, 2007). Suitability refers to the fitness of one specific use (e.g. conservation, urban, and agricultural lands) in an area. Preference reflects the opinion of the community, in other words, what the community wants. Conflictive areas are the ones that cannot be urbanized for several reasons (e.g. forest conservation lands) (Carr and Zwick, 2007). Based on these three concepts the most suitable areas for urban development were identified by Zwick and Carr (2006). The final output was a raster file with the predicted urban areas for 2060. The 2060-Population distribution map was combined with the 2003-Florida vegetation map to update and produce the 2060 urbanization scenario-Land cover map using ArcGIS® Spatial Analyst. For the carbon and timber model, the 2060-Florida vegetation map was used; this was the result of the extraction of the forest covers from the 2060-Florida vegetation and land use. This raster was combined with the ecological subsection and county layers. However, for the water yield model all land cover types were considered in the analysis.

Statistical differences between the 2003 and the 2060 urbanization map at the sub-watershed level were determined using a two tail t-test with two paired samples for means at 95% confidence level. A Pearson correlation coefficient was calculated between carbon storage, timber volume, and water yield, as well as between each of them and the amount of forest areas. The analyses were done at the sub-watershed level and Microsoft Excel® (Microsoft, 2010) was used for both calculations.

Results

Carbon Storage in 2003 and Urbanized 2060

In 2003, the total carbon storage in the Lower Suwannee River watershed was 36,586,750 Mg. The total carbon storage ranged from 72 to 342 Mg/ha with an average of 196 Mg/ha. However, in 2060, the total carbon storage was 30,638,160 Mg with a minimum and maximum value of 69 and 326 Mg/ha, respectively. The average total carbon for the watershed was 187 Mg/ha (Table 2-8). A reduction of 5,948,590 Mg of total carbon (19%) occurred due to urbanization. The highest carbon values in 2003-2060 correspond to the soil and aboveground pools (Table 2-9). In 2003, the total carbon aboveground was 10,193,638 Mg with an average value of 55 Mg/ha. In 2060, the total aboveground carbon was 8,467,580 Mg with an average of 52 Mg/ha. The highest average values of total carbon were concentrated in the northern part of the watershed (Table 2-9 and Figure 2-6), which corresponded to the mixed wetland forest and hardwood swamp in the Gulf Coastal Lowlands (232Db) and Florida Northern Highlands (232Ka) ecological subsections, respectively. The lowest value corresponded to the sandhill ecological subsection 232Ka.

There was a reduction in the mean carbon value due to urbanization across all 63 sub-watersheds that ranged from 4 to 26 Mg/ha. The largest difference was observed in the Waccasassa Slough sub-watershed (Id 49), where the mean carbon storage in 2003 was 183 Mg/ha, and in 2060 this value decreased to 156 Mg/ha with a reduction of 26 Mg/ha. In this sub-watershed there was a decrease in forest area of 14% and an increase of 40% in urban areas. The largest changes were observed in the hardwood hammock forests and the pinelands. The smallest difference was observed in the sub-watershed id 39 (Rock Bluff Spring), which had a forest area reduction of 7% and an increase of 18% in urban areas (Figures 2-6, 2-8). Differences in mean total carbon storage between sub-watersheds for the period 2003 and 2060 were statistically significant at 95% confidence level (Table 2-9).

In the Pensacola Bay in 2003, the total carbon storage in forest was 7,998,265 Mg with an average of 148 Mg/ha, with 66 and 229 Mg/ha as minimum and maximum values (Figure 2-7). However, in 2060, the total carbon storage decreased to 5,866,804 Mg with a minimum and maximum value of 64 and 218 Mg/ha, respectively. The average total carbon for the watershed was 137 Mg/ha. The forest area was reduced by 11,212 ha, with a resulting reduction of 2,131,461 Mg of total carbon (Table 2-8). The carbon aboveground in the watershed was 1,396,430 Mg, representing the 17% of the total carbon storage in the Pensacola Bay watershed (Table 2-9); however, in 2060 this value was 1,015,730 Mg. The highest total carbon was observed in the Bay Swamp within the ecological subsection denominated 232Bg. The lowest value was for the Hardwood Hammocks and Forest in the ecological subsection named Florida Gulf Coast Flatwoods (232Lb).

At the sub-watershed level in the Pensacola Bay watershed, there was a reduction in the mean total carbon in the 15 sub-watersheds from 3 to 18 Mg/ha. The largest difference was observed in the Fundy Bayou-Williams Creek Frontal sub-watershed (Id 11), where the mean carbon was 162 Mg/ha in 2003 and 144 Mg/ha in 2060 with a reduction of 18 Mg/ha. Regarding the land use change in this sub-watershed, the forest area was reduced by 34% and the urban area increased by 36%. The largest changes were found the Pineland areas (Figures 2-9, 2-10). A t-test using two paired samples for means was conducted to find differences in mean total carbon between sub-watersheds due to urbanization and differences were significant at 95% confidence level (Table 2-9).

Timber Volume in 2003 and Urbanized 2060

The average timber net volume (volnet) for the Lower Suwannee in 2003 was 109 m^3/ha and a total timber net volume of 20,402,395 m^3 approximately over an area of 186,275 ha of forest. However, for 2060, the average timber net volume was 110 m^3/ha within an area of 163,692 ha, giving an approximate total net volume 18,100,416.54 m^3. Therefore, the urbanization in the Lower Suwannee watershed produced a decrease of 2,301,978.47 m^3 in the timber net volume, as a result of the loss of 22,583 ha of forest; this despite of an increase in timber volume of 1.72% (Prestemon and Abt, 2002b). The timber volume in the sawlog portion, in 2003 was 15,477,193.37 m^3 with an average of 83 m^3/ha.

However, in 2060, the timber volume in the sawlog portion was 13,540,937.07 m^3 with an average of 83 m^3/ha and a reduction of 1,936,256.24 m^3 of timber in the sawlog portion (Table 2-10). Higher values were observed in the 2003 compared to 2060. The highest timber net volume corresponded to the northeast part of the watershed and to the Pinelands located in the Florida Northern Highlands (232Ka) ecological subsection. At the sub-watershed level in 2003 the largest decrease (17%) in mean timber net volume was for the Waccasassa Slough sub-watershed (Id 49). This sub-watershed had a decrease in forest area of 14% and an increase in urban areas of 40%. A t-test using two paired samples for means was conducted to find that differences between the mean timber net volume in 2003 and 2060 were statistically significant at 95% confidence level (Table 2-10).

For Pensacola Bay, the average timber net volume in 2003 was 69 m^3/ha in an area of 54,381 ha and total timber net volume was approximately 3,730,642 m^3. However, for the year 2060, there was a reduction of 11,514 ha of forest that produced a decrease of 800,909 m^3 of timber net volume. For sawlog timber volume, in 2003 the volume was approximately 2,980,362.85 m^3 with an average of 68.344 m^3/ha. However, in 2060, the sawlog timber volume was approximately 2,309,369 m^3 (Table 2-10). The highest timber net volume corresponded to the Pinelands located in the ecological subsection named Florida Gulf Coast Flatwoods (232Lb). At the sub-watershed level, in 2060 there was a decrease in the mean timber net volume in 13 out of 15 sub-watersheds. The largest difference (6 m^3/ha) in the mean timber net volume was observed in the Williams Creek-Oriole Beach Frontal sub-watershed (Id 11). In this sub-watershed there was a decrease of 34% of forest and an increase of 36% of urban areas. The t-tests showed statistically significant differences between sub-watersheds for 2003 and 2060 at 95% confidence level (Table 2-10).

Water Yield in 2003 and Urbanized 2060

Mean annual water yield for the Lower Suwannee River watershed in 2003 was 1,293 mm and water yield volume of 12,932 m^3/ha. However, in 2060, the mean precipitation and PET as was mean annual water yield (1,342 mm) (Table 2-11) and volume (13,422 m^3/ha) were greater than 2003. The highest values of water yield were located in the south part of the watershed and lowest values were located in the north part of the watershed, where most of the forest areas are located.

At the sub-watershed level, there were increases in water yield, precipitation, and PET for the Lower Suwanee's water yield in 2060. The largest difference in mean annual water yield between 2003 and 2060 was observed in the Barnett Creek sub-watershed (Id 1), where there was an increase of 152 mm/year and the largest increase in precipitation in 2060 but no changes in land use/cover. In the 63 sub-watersheds there was more water yield per hectare in 2060 (Figure 2-8). The t-test showed that the differences in water yield volume were statistically significant at 95% confidence level (Table 2-11).

In 2003 the Pensacola Bay the annual water yield was 1,520 mm and the average water yield per hectare was 15,319 m^3. However, in 2060 the precipitation and PET were higher as were annual water yield at 1,578 mm and water yield per hectare at 15,776 m^3. At the sub-watershed level, the largest increase in mean annual water yield was observed in the Bayou Cico-Bayou Garcon Frontal sub-watershed (id 15) that registered the largest increase in precipitation in 2060 and there is a high positive correlation (r=0.969) between the difference in annual water yield and difference in precipitation (Figure 2-9). There was also a decrease in the forest area and an increase in the urban areas. The t-test showed statistically differences in the water yield volume between sub-watersheds for 2003 and 2060 at 95% confidence level (Table 2-11).

Water Yield Assessment for the Lower Suwannee River Watershed

Results show that there were differences between the average water volume from the Gopher gage station and the average water yield estimated from the model. The average value from the model was 5,184,553,019 m^3 and the average from the gage station was higher 6,722,705,162 m^3 (Table 2-12). However, when the values were normalized, the trends between both curves (i.e. modeled and measured water yield) were similar (Figure 2-10).

Tradeoffs Between Carbon Storage, Timber Volume, Water Yield, and Urbanization

Tradeoffs were evident between carbon storage, timber volume and water yield in both watersheds. In the 2060 urbanized scenario, carbon storage and timber volume were lower than the 2003; however, water yield was higher in 2060 (Figure 2-11). Also, a positive correlation was observed between carbon storage and timber volume, and a negative correlation with water yield (Table 2-13). Because the loss of forest areas in this study is the result of urbanization, it can thus be surmised that carbon storage and timber volume decrease when urban areas increase. However, water yield increase when forest areas decrease or urban areas increase, but the correlation was weakly negative (Table 2-13).

Discussion

The study hypothesis was accepted, thus urbanization, ignoring the ecosystem service provision in urban areas, directly affects carbon storage, timber volume, and water yield. Carbon storage and timber volume were high negatively correlated to urbanization in both watersheds and water yield was high positively correlated in the Lower Suwannee watershed and weak positively correlated in the Pensacola Bay watershed. Results showed that urbanization will convert forest areas by the year 2060, and this will result into the decrease of the provision of carbon storage and timber volume, and into an increase in water yield that will statistically be significant differences at 95% confidence level.

Carbon Storage in 2003 and Urbanized 2060

Aboveground and soil carbon accounted for about 50-80% of the total carbon storage in both watersheds (Table 2-9) and store the largest amount of carbon in forests (Huggett et al., 2002; Lal, 2005; Moore et al., 2002). The mean total carbon storage for the Lower Suwannee and Pensacola Bay watershed were 196 and 148 Mg/ha respectively for the year 2003 (Table 2-8). These values were within the range reported by Heath et al. (2011) for forest areas in the United States, where the mean was 162 Mg of carbon per ha, and ranged from 150 Mg/ha to 192 Mg/ha. According to Timilsina et al. (2011) carbon pools average for Florida forests were 165 Mg of carbon per ha in cold spots (i.e. clusters of lower carbon storage values) and 177 Mg of carbon per ha in hot spots (i.e. clusters of higher carbon storage values). Lal (2005) mentioned an average of 60-130 Mg C/ha in temperate forests and 120-194 Mg of carbon per ha in tropical forests. However, carbon storage decreased by 16% and 26% in the 2060 land use scenario in the Lower Suwannee and Pensacola Bay watersheds, respectively.

Escobedo et al. (2009a) presented a comparison of average carbon storage by urban forests in Florida that ranged from 9.3 Mg per hectare in Miami-Dade County, 27.4 Mg per hectare in Southern Escambia County, and 30.8 Mg per hectare in Gainesville. Using this study's 2003 average forest carbon storage values and average carbon storage for Southern Escambia's urban forests (Escobedo et al., 2009a), the total carbon storage for the Pensacola Bay watershed will be about 175.4 Mg/ha. Therefore, the amount of carbon stored in the Pensacola Bay watershed 's urban forests is about 16% of the total carbon storage (i.e. 175.4 Mg/ha). Using the former total carbon storage value that includes both urban and natural forests, total carbon storage in the urbanized 2060 scenario in Pensacola Bay watershed decreased 26%

when compared to the 2003 total carbon storage. So, even if carbon stored in urban forests were included in this analysis; there would still be an overall decrease in total carbon storage in the Pensacola Bay watershed from 2003 to 2060.

This reduction in C storage was a combination of the increased urbanization as well as the 5% reduction in the carbon pools considered in the analysis for 2060. Since the decreases in both study areas were greater than 5%, urbanization and not the assumed 5% carbon reduction loss, was the main driver for this decrease. In Pensacola Bay, the forest area losses due to urbanization were 21%, and corroborates studies that show that land use change as an important driver affecting carbon storage and sequestration in ecosystems (Birdsey et al., 2006; Moore et al., 2002; Reyers et al., 2009), as well as diseases, pests, hurricanes, and fires (McNulty, 2002). Also urbanization is the dominant land use change that affects southern forests (Conner and Sheffield, 2006; Nowak et al., 2005; Wear and Greis, 2002b) and Wear and Greis (2002a) mentioned that 30-43 million acres of land are likely to be converted to urban land uses by 2060 in the Southern United States.

At the sub-watershed level, both watersheds showed reductions of carbon storage and the largest differences between 2003 and 2060 were observed in sub-watersheds where forest ecosystems have decreased and urban areas increased. This indicates that urbanization generates forest losses and carbon emissions (Wear and Greis, 2002b). Huggett et al. (2002) developed some scenarios assuming high and low urbanization and the highest amount of carbon storage in 2060 was for the low-urbanization scenario, and the lowest carbon storage was for the high urbanization scenario. This study’s two watersheds were very different in terms of distribution of land cover in the year 2003 since Pensacola Bay was more urbanized than Lower Suwannee (30% and 6%) (Table 2-1), therefore the percentage of carbon storage in the Pensacola Bay was lower because of a higher percentage of urbanization, and was thus the most impacted watershed in 2060.

Timber Volume in 2003 and Urbanized 2060

The Lower Suwannee had 11% less timber volume in 2060 compared to 2003; however, the Pensacola Bay had a larger decrease (21%) (Table 2-10). As mentioned before, the Pensacola Bay is more impacted by urbanization. The same situation applied to the timber in the sawlog portion. At the sub-watershed level, both watersheds reported the largest changes between 2003 and 2060 in areas where the forest area has been decrease and urban area has been increased. Two main factors are considered important in terms of forest loss: urbanization and timber prices, because the first one comprises land use change and the second one can increase levels of timber harvest (Huggett et al., 2002). According to Conner & Hartsell (2002), Florida has lost most of the forest areas due to urbanization; however, timber prices are projected to increase. Hodges et al. (1998) found that the forest area was reduced by urbanization by 25% compared to this study's 12% and 21% in the Lower Suwannee and Pensacola Bay watersheds respectively (Table 2-10). Munn et al. (2002) mentioned that urbanization affects timber harvesting possibilities because of the decrease in the forest area.

Water Yield in 2003 and Urbanized 2060

In both watersheds the water yield was higher in 2060; as well as the precipitation and potential evapotranspiration. Based on data produced by the CSIRO Mk3 model precipitation and evapotranspiration will increase in the next years and according to several studies (Alvarez et al., 2001; Florida Oceans and Coastal Council, 2009; Furniss et al.). Increase in water yield is due to two main factors: increase in precipitation, the primary driver of water yield (Dymond et al., 2012; Sun et al., 2005) and changes in land use/cover. A high correlation factor (0.9) between precipitation and water yield can be observed. In the case of changes in land use/cover, many studies proved that water yield is lower in forested areas (Bosch and Hewlett, 1982; Dymond et al., 2012; Hibbert, 1965). Bosch & Hewlett (1982) found that forests decrease water yield, for example for deciduous hardwoods and coniferous there is a 25 mm and 40 mm change in water yield respectively per 10% change in cover. This value was close to the one obtained in this study; in the Lower Suwannee there was a 12% change in cover and a 49 mm change in water yield. However, in the Pensacola Bay there was a 21% change in forest cover and a 57 mm change in water yield. However, Swank et al. (2001) identified a 28% increase in water yield after forest harvesting due to reduction in total ecosystem evapotranspiration and the increase in runoff. Even, Dymond et al. (2012) mentioned that there is a reduction between 30%-50% in the water yield because of new forest areas. Since water yield is highly influenced by precipitation, the percentage of increase will depend on the characteristics of the site. Swank et al. (2001) did the study in western North Carolina where annual precipitation ranges from 1,700 mm to 2,500 mm. In many sub-watersheds, the increase in water yield was the result of the increase in precipitation, decrease in potential evapotranspiration, and decrease in forest areas (Dymond et al., 2012).

Water Yield Assessment

The differences in absolute values for the InVEST model and the gauging station were large in most analyzed years (Table 2-12). These differences could be related to the groundwater discharge, according to Katz et al. (1997) this watershed is characterized by the presence of karst features that enable the interaction between the groundwater and surface water. Therefore, groundwater is an important component in this watershed; however the InVEST model does not account for it. This situation can be considered a problem in the case where absolute values are important for example if the water will be used for irrigation, so in this case the model should be calibrated.

Tradeoffs Between Carbon Storage, Timber Volume, Water Yield, and Urbanization

Tradeoffs arise when the increase in use of one ecosystem service can decrease the use of another service (Rodriguez et al., 2006). Therefore, when forests are managed for increased carbon storage, tradeoffs can arise as seen in the two studied watersheds. Carbon storage and timber volume were highly positive correlated (Table 2-13), so the increase in carbon storage results in an increase in timber volume (Figure 2-11). However if timber production is taken into account, this relationship was negative; an increase in timber harvesting will result in a decrease in carbon storage in live trees (in situ). There is also carbon storage in wood products (ex situ) and this pool can store considerable amounts of carbon (Seidl et al., 2007). The ex situ carbon was not considered in this analysis. Timber harvesting can provide positive benefits in economic terms but also there are some negative effects in ecological terms because of the loss in forest area, such as release of carbon to the atmosphere, increase in flooding, and climate regulation (Dymond et al., 2012; Raudsepp-Hearne et al., 2010).

Water yield was, however, inversely related to carbon storage and timber volume (Table 2-13) (Dymond et al., 2012). There was an increase in water yield with decrease in forest areas and this can considered as both a negative and a positive thing depending on the characteristics of the watershed. For example if there is a demand for irrigation water, less water yield is a negative thing; however, the increase in water yield can result in an increase in flooding and in soil erosion, because more water is moving faster over the surface (Dymond et al., 2012). In general terms, increase in provisioning services will result in a decrease in regulating services (Dymond et al., 2012; Raudsepp-Hearne et al., 2010). Urbanization, as a result of this study is the responsible of the forest area losses. So, urbanization was negatively correlated to carbon storage and timber volume and positively correlated to water yield (Table 2-13). According to Escobedo et al. (2009a) the average carbon storage for urban forests in Southern Escambia County in the Pensacola Bay watershed is 27.4 Mg per hectare, so this carbon value is much lower when compared to forest areas analyzed in this study.

The key point is to reduce tradeoffs between ecosystem services, as well as between ecosystem services and urbanization. This is complicated because the interactions between ecosystem services are complex (Dymond et al., 2012), in addition to the difficulty in finding the balance between the use of different ecosystem services (DeFries et al., 2004). DeFries et al. (2004) referred to the problem of finding the balance between human needs (e.g. new urban areas) and ecological functions of ecosystems. Therefore, the starting point for assessing tradeoffs is to quantify ecosystem services and to know about the response of ecosystems to different land use changes (e.g. urbanization) (DeFries et al., 2004). This can be understood as the inclusion of ecological knowledge in the land-use decisions (DeFries et al., 2004). One alternative proposed by DeFries et al. (2004) and Gimona and van der Horst (2007) is to identify the “win-win” and “lose-lose” areas were urbanization produces neither positive or negative consequences in the ecosystem services. Then, areas where the ecosystem services will suffer less impact should be selected for new development.

Concluding Remarks

Urbanization reduces forest area thus affecting its functions and the provision of services, and consequently human well-being. Even though, there are tradeoffs between ecosystem services and between human needs and ecological functions, some management alternatives can be used for reducing these tradeoffs. Some key challenges in terms of ecosystem management are related to better knowing about the ecosystem services in biophysical terms (e.g. Mg of carbon storage) and to understand how ecosystem services are linked, their tradeoffs, as well as the effects of drivers on them. However, to develop alternatives for reducing these tradeoffs and consequently to produce less impacts on ecosystems and people is not simple.

Further, spatial mapping and quantifying ecosystem services is not an easy task. The use of the Integrated and Valuated Ecosystem Services and Tradeoffs (InVEST) model, the USDA FIA field data, and other Geographic Information System (GIS) data analysis provided a viable method to spatially map ecosystem services such as carbon storage and water yield despite some limitation. The advantage of the InVEST model is that is simple, so little data is needed and can be used in areas with poor data availability. However, there are also some limitations, for example the water yield model does not account for the groundwater, and this situation generates a large difference in absolute water yield values when comparing to real data from gauge stations. Nevertheless, as shown in Figure 2-9 the model can predict trends in water yield very well and most importantly models can not reflect the complexity of the real world, but they can approximate processes.

The FIA field data provide information that can be used in several approaches such as for determining the values for different carbon pools and timber volume in the study area. However, data limitation is the exact plot position (latitude/longitude), plots displacement of plus or minus ½ or 1 mile because of privacy rights. A different approach was used in this analysis for dealing with this limitation; some attributes from the FIA data such as FIA Survey Unit, County, and Ecological subsection were used for specifying carbon and timber data. The potential of this FIA database is large, and several analysis based on GIS could be done if the FIA plot geographic coordinates were available.

Future research can include other ecosystem services in the analysis to better have a complete idea of the interactions between ES. One ecosystem can provide multiple services at the same time; therefore all of them need to be considered in the analysis. These services can be water quality, erosion control, food, recreation, among others. Similarly, the analysis of other direct and indirect drivers is recommended. A climate change scenario could be very interesting, as well, as different forest management scenarios.

The results provided in this study are useful for land planners for balancing ecological information with human needs and to include this ecological information in land decisions. Land planners would know the quantity of ecosystem services that can be lost when a forest area is converted into an urban area. This information should be part of the decision-making processes. Results can also be used for maximizing human well-being by maximizing all the services provided by ecosystems, as well as reducing the tradeoffs between them, and the valuation of ecosystem services. The first step for valuing ecosystem services is to quantify their production functions; the second one is to assign an economic value to these functions. Knowing the value of the ecosystem services and the effects of drivers influencing them is important when developing payments for ecosystem services as a conservation tool. Payment for ecosystem services is becoming an important mechanism to achieve the balance between human and natural well-being. Forecasting land use change will also show how human needs (new urban areas) can alter ecosystem and its services and how ecosystems respond to these changes.

Table 2-1. Land cover distribution in the Lower Suwannee River and Pensacola Bay watersheds, Florida based on the Florida Fish and Wildlife Conservation Commission

Number	Land cover	Type	Pensacola Bay		Lower Suwannee	
			Area (ha)	%	Area (ha)	%
1	Coastal Strand		1,034	0.7	------	------
2	Sand/Beach		2,173	1.5	1	0
3	Xeric Oak Scrub		121	0.1	------	------
4	Sand Pine Scrub (*)	S	489	0.4	------	------
5	Sandhill (*)	S	15,018	10.7	3,352	0.8
6	Dry Prairie		------	------	259	0.1
7	Mixed Pine-Hardwood Forest (*)	H	3,745	2.7	10,561	2.6
8	Hardwood Hammocks and Forest (*)	H	2,144	1.5	38,880	9.5
9	Pinelands (*)	S	18,475	13.1	97,118	23.8
12	Freshwater Marsh and Wet Prairie		2,124	1.5	2,599	0.6
15	Shrub Swamp		217	0.2	8,579	2.1
16	Bay Swamp (*)	S	5,969	4.2	187	0.1
17	Cypress Swamp (*)	S	399	0.3	12,724	3.1
18	Cypress/Pine/Cabbage Palm (*)	S	------	------	0.27	0
19	Mixed Wetland Forest (*)	H	4,486	3.2	9,325	2.3
20	Hardwood Swamp (*)	H	3,629	2.6	13,538	3.3
21	Hydric Hammock (*)	H	------	------	590	0.1
23	Salt Marsh		136	0.1	2,148	0.5
26	Tidal Flat		17	0	0.09	0
27	Open Water		48,597	34.5	6,706	1.6
28	Shrub and Brushland		1,922	1.4	43,910	10.7
29	Grassland		38	0	11	0
30	Bare Soil/Clearcut		412	0.3	30,694	7.5
31	Improved Pasture		10	0.01	74,320	18.2
32	Unimproved Pasture		------	------	2,841	0.7
35	Row/Field Crops		1,098	0.8	21,098	5.2
36	Other Agriculture		25	0	3,824	0.9
41	High Impact Urban		24,181	17.2	12,705	3.1
42	Low Impact Urban		4,365	3.1	12,843	3.1
43	Extractive		------	------	17	0
	Total		140,825	100	408,828	100

* Land cover used in the carbon storage and timber volume analysis; H, hardwoods; S, softwoods

Table 2-2. Ecological subsection (Ecol. Subs.) descriptions. [Adapted from McNab, W. H., Cleland, D. T., Freeouf, J. A., Keys, J., J.E., Nowacki, G. J., and C. A. Carpenter. 2007. Description of Ecological Subregions: Sections of the Conterminous United States. U.S. Department of Agriculture, Forest Service. Washington.]

Ecol. Subs.	Name	Description	Mean annual Temperature (°F)	Annual Precipitation (mm)
232Bg	Gulf Coastal Plains and Flatwoods Section	Flat topography. Natural vegetation consists of longleaf-slash pine, loblolly-shortleaf pine, and oak-hickory cover types, with oak-gum-cypress along rivers.	67	1,587
232Bj	Gulf Coastal Plains and Flatwoods Section	Flat topography. Natural vegetation consists of longleaf-slash pine, loblolly-shortleaf pine, and oak-hickory cover types, with oak-gum-cypress along rivers.	65	1,553
32Db	Florida Coastal Lowlands-Gulf Section	Generally flat topography. Vegetation is mostly longleaf-slash pine and oak-gum-cypress cover types.	72	1,303
232Jf	Southern Atlantic Coastal Plains and Flatwoods section	Terrain is weakly dissected irregular. Vegetation is mainly a mixture of loblolly-shortleaf pine, longleaf slash pine, oak-pine, and oak-gum-cypress cover types.	66	1,262
232Ka	Florida Coastal Plains Central Highlands Section	Terrain is hilly with excessively drained. Forests consist of longleaf-slash pine and oak-hickory cover types. Much of the original forest vegetation has been removed and replaced by highly cultivated citrus groves. Section is ecologically significant because environments are drier than adjacent units.	68	1,393

Table 2-2. Continued

Ecol. Subs.	Name	Description	Mean annual Temperature (°F)	Annual Precipitation (mm)
232Lb	Gulf Coastal Lowlands Section	Flat topography. Vegetation is mostly longleaf-slash pine and oak-gum-cypress cover types.	67	1,627
232Lc	Gulf Coastal Lowlands Section	Flat topography. Vegetation is mostly longleaf-slash pine and oak-gum-cypress cover types.	68	1,473

Table 2-3. Description of the Forest Inventory and Analysis (FIA) attributes used in the carbon and timber analysis. [Adapted from Woudenberg, S. W., Conkling, B. L., O'Connell, B. M., LaPoint, E. B., Turner, J. A., and K. L. Waddell. 2010. The Forest Inventory and Analysis Database: Database Description and User's Manual Version 4.0 for Phase 2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO.]

Attribute code	Attribute	FIA Table name	Attribute description
UNITCD	FIA Survey unit	Condition, Tree, Plot	Survey units are groups of counties within each State
PLT_CN	Plot sequence number	Condition, Tree, Plot	Unique number to identify plots
ECOSUBCD	Ecological Subsection	Plot	An area of similar surficial geology, lithology, geomorphic process, soil groups, sub-regional climate, and potential natural communities
COUNTYCD	County	Condition, Tree, Plot	The identification number for a county, a governmental unit in a State
COND_STATUS_CD	Condition status	Condition	The condition status indicates the basic land cover (e.g. forest land)
STDAGE	Stand age	Condition	The average age of the stand
SPCD	Species code	Tree	A FIA tree species code
FORTYPCD	Forest description	Condition	Forest type code

Table 2-4. Forest tree species used in the carbon storage and timber volume analysis by Land cover type

Scientific name	Forest Inventory and Analysis code	Land Cover number										
		4	5	7	8	9	16	17	18	19	20	21
Acer rubrum	316							X		X	X	
Carpinus caroliniana	391			X	X							
Carya glabra	403			X	X							
Carya tomentosa	400			X	X							
Chamaecyparis thyoides	43						X					
Cornus florida	491			X								
Fagus grandifolia	531			X	X							
Fraxinus americana	541			X	X							
Fraxinus caroliniana	548									X	X	
Gordonia lasianthus	555						X					
Ilex cassine	7455									X	X	
Ilex opaca	591			X	X							
Juniperus silicicola	57											X
Liquidambar styraciflua	611			X	X							X
Magnolia grandiflora	652			X	X							
Magnolia virginiana	653						X	X		X	X	
Morus rubra	682			X	X							
Nyssa aquatic	691									X	X	
Nyssa sylvatica var. *biflora*	693						X	X		X	X	
Ostrya virginiana	701			X	X							
Persea palustris	720						X					
Pinus clausa	107	X								X		

4: Sand Pine Scrub, 5: Sandhill, 7: Mixed Pine-Hardwood Forest, 8: Hardwood Hammocks and Forest, 9: Pinelands, 16: Bay Swamp, 17: Cypress Swamp, 18: Cypress/Pine/Cabbage Palm, 19: Mixed Wetland Forest, 20: Hardwood Swamp, 21: Hydric Hammock

Table 2-4. Continued

Scientific name	Forest Inventory and Analysis code	Land Cover number										
		4	5	7	8	9	16	17	18	19	20	21
Pinus echinata	110			X						X		
Pinus elliottii	111			X		X	X		X	X		
Pinus glabra	115			X	X					X		
Pinus palustris	121		X	X		X			X	X		
Pinus serotina	128					X	X		X	X		
Pinus taeda	131			X		X			X	X		
Quercus chapmanii	800	X										
Quercus falcate	812			X	X							
Quercus geminate	800	X		X	X							
Quercus incana	842		X	X	X							
Quercus laevis	819		X									
Quercus laurifolia	820			X	X							X
Quercus lyrata	822			X	X							
Quercus marilandica	824			X	X							
Quercus myrtifolia	800	X										
Quercus nigra	827			X								
Quercus shumardii	834			X	X							
Quercus stellata var. *margaretta*	835			X	X							
Quercus virginiana	838			X	X							X
Sabal palmetto	912			X	X				X	X	X	X
Taxodium ascendens	222						X	X	X			
Taxodium distichum var. *distichum*	221						X	X	X	X	X	
Tilia americana	951			X	X							

4: Sand Pine Scrub, 5: Sandhill, 7: Mixed Pine-Hardwood Forest, 8: Hardwood Hammocks and Forest, 9: Pinelands, 16: Bay Swamp, 17: Cypress Swamp, 18: Cypress/Pine/Cabbage Palm, 19: Mixed Wetland Forest, 20: Hardwood Swamp, 21: Hydric Hammock

Table 2-5. Carbon pools aggregation based on the information available in the Forest Inventory and Analysis (FIA) Program database

Carbon pools	FIA Carbon data
Aboveground biomass	Carbon aboveground + carbon understory aboveground
Belowground biomass	Carbon belowground + carbon understory belowground
Soil organic matter	Carbon soil
Dead biomass	Carbon litter + carbon standing dead + carbon down dead

Table 2-6. Reclassified land cover and carbon pools for the Pensacola Bay watershed

Raster value	Original LC	Eco subs	County	C above	C below	C soil	C dead	LC name
1	9	232Bj	113	44.63	9.91	107.59	17.39	Pinelands
2	7	232Bj	113	63.91	13.93	49.84	11.82	Mixed Pine-Hardwood Forest
3	8	232Bj	113	14.68	2.72	49.84	11.82	Hardwood Hammocks and Forest
4	20	232Bj	113	10.92	2.08	174.04	13.62	Hardwood Swamp
5	19	232Bj	113	55.27	12.17	121.21	18.15	Mixed Wetland Forest
6	9	232Bg	113	42.62	9.48	107.59	16.77	Pinelands
7	8	232Bg	113	24.05	3.57	49.84	8.54	Hardwood Hammocks and Forest
8	7	232Bg	113	66.50	13.32	49.84	8.54	Mixed Pine-Hardwood Forest
9	20	232Bg	113	11.07	2.07	174.04	25.38	Hardwood Swamp
10	19	232Bg	113	68.13	15.28	125.20	18.61	Mixed Wetland Forest
11	16	232Bg	113	51.68	11.27	147.63	20.23	Bay Swamp
12	9	232Lb	113	31.90	7.06	121.21	18.59	Pinelands
13	7	232Lb	113	38.91	8.49	49.84	13.76	Mixed Pine-Hardwood Forest
14	8	232Lb	113	10.29	1.80	49.84	13.76	Hardwood Hammocks and Forest
15	20	232Lb	113	3.23	0.49	174.04	5.06	Hardwood Swamp

LC, Land cover; Eco subs, ecological subsection; C, carbon

Table 2-6. Continued

Raster value	Original LC	Ecol subs	County	C above	C below	C soil	C dead	LC name
16	19	232Lb	113	33.02	7.39	147.63	12.23	Mixed Wetland Forest
17	16	232Lb	113	22.64	4.94	147.63	12.23	Bay Swamp
18	5	232Bg	113	15.48	3.23	67.64	16.58	Sandhill
19	5	232Bg	91	14.77	2.88	67.64	14.85	Sandhill
20	9	232Bg	91	32.10	7.03	107.59	16.44	Pinelands
21	7	232Bg	91	50.53	10.80	49.84	12.87	Mixed Pine-Hardwood Forest
22	16	232Bg	91	45.55	9.79	147.63	20.23	Bay Swamp
23	20	232Bg	91	26.03	5.38	174.04	15.16	Hardwood Swamp
24	19	232Bg	91	52.90	13.90	125.20	17.05	Mixed Wetland Forest
25	8	232Bg	91	19.27	3.62	49.84	12.87	Hardwood Hammocks and Forest
26	5	232Lb	113	19.47	4.05	67.64	15.01	Sandhill
27	20	232Bg	33	5.44	0.94	174.04	20.27	Hardwood Swamp
28	19	232Bg	33	48.90	10.80	125.20	17.83	Mixed Wetland Forest
29	7	232Bg	33	116.30	21.48	49.84	16.00	Mixed Pine-Hardwood Forest
30	9	232Bg	33	45.80	10.12	80.33	16.87	Pinelands
31	8	232Bg	33	62.66	11.78	49.84	16.00	Hardwood Hammocks and Forest
34	16	232Bg	33	10.95	2.07	147.63	20.23	Bay Swamp
36	17	232Bg	33	5.44	0.94	174.04	20.27	Cypress Swamp
37	17	232Lb	113	3.23	0.49	174.04	5.06	Cypress Swamp
40	5	232Lb	91	12.47	2.32	67.64	8.96	Sandhill
41	9	232Lb	91	18.97	4.08	121.21	20.65	Pinelands
42	20	232Lb	91	5.12	0.88	174.04	5.06	Hardwood Swamp
43	19	232Lb	91	40.48	9.12	100.77	22.42	Mixed Wetland Forest
44	8	232Lb	91	10.92	1.91	49.84	13.76	Hardwood Hammocks and Forest

LC, Land cover; Eco subs, ecological subsection; C, carbon

Table 2-6. Continued

Raster value	Original LC	Ecol subs	County	C above	C below	C soil	C dead	LC name
45	7	232Lb	91	27.51	5.84	49.84	13.76	Mixed Pine-Hardwood Forest
46	16	232Lb	91	12.72	2.70	121.21	22.56	Bay Swamp
47	17	232Bg	91	26.03	5.38	174.04	15.16	Cypress Swamp
48	17	232Lb	91	4.72	0.79	174.04	5.06	Cypress Swamp
51	4	232Lb	113	3.59	0.47	80.33	23.65	
52	7	232Lb	33	31.68	6.93	49.84	13.76	Mixed Pine-Hardwood Forest
53	9	232Lb	33	30.92	6.76	121.21	18.17	Pinelands
54	16	232Lb	33	33.04	7.14	121.21	18.17	Bay Swamp
55	8	232Lb	33	4.25	0.56	49.84	13.76	Hardwood Hammocks and Forest
56	20	232Lb	33	6.21	1.09	174.04	5.06	Hardwood Swamp
57	19	232Lb	33	47.72	10.57	100.77	21.60	Mixed Wetland Forest
58	17	232Lb	33	5.82	1.00	174.04	5.06	Cypress Swamp
59	4	232Lb	91	25.07	5.44	80.33	22.28	Sand Pine Scrub
61	4	232Lb	33	15.76	3.29	80.33	25.02	Sand Pine Scrub

LC, Land cover; Eco subs, ecological subsection; C, carbon

Table 2-7. Input data for the InVEST water yield model. [Adapted from Tallis, H., Ricketts, T., Guerry, A., Wood, S., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C., Guannel, G., Papenfus, M., Toft, J., Marsik, M., and J. Bernhardt. 2011. Invest 2.2.2 User's Guide. The Natural Capital Project. Stanford.]

Data	Description	Units	Data Source
Soil depth–GIS Raster	Minimum of depth to bedrock and typical water table depth.	mm	Soil Survey Staff, Natural Resources Conservation Service, USDA (2006)
Precipitation–GIS Raster	A non-zero value for average annual precipitation for each cell (1998-2008)	mm	PRISM Climate Group & Oregon State University (2008)
Plant Available Water Content-GIS Raster	Fraction of water that can be stored in the soil profile that is available for the use of plants.		Soil Survey Staff, Natural Resources Conservation Service, USDA (2006)
Average Annual Potential Evapotranspiration–GIS Raster	Potential loss of water from soil by both evaporation from the soil and transpiration by healthy Alfalfa, if sufficient water is available (1998-2008)	mm	U.S Geological Survey, Florida Water Science Center (2008)
Land cover-GIS Raster	A LC code for each cell (2003)		Florida Fish and Wildlife Conservation Commission (2004)
Watershed–GIS Shapefile	The boundary of one drainage area		Natural Resources Conservation Service (2005)
Sub-watershed–GIS Shapefile	Subdivision of watersheds		Natural Resources Conservation Service (2005)
Maximum root depth (per land cover type)	Maximum root depth for vegetated land covers	mm	Canadell et al. (1996) U.S. Department of Agriculture Forest Service

Table 2-7 Continued

Data	Description	Units	Data Source
Evapotranspiration coefficient (etk; per land cover type)	The plant evapotranspiration considering the transpiration characteristics to modify the reference evapotranspiration, which is based on alfalfa		
Zhang Constant (per watershed)	Corresponds to the seasonal distribution of precipitation.		Tallis et al. (2011)

Table 2-8. Carbon storage descriptive statistics for the Lower Suwannee (LS) and Pensacola Bay (PB) Florida watersheds in Mg/ha

Watershed	Year	Forest area (ha)	Minimum	Maximum	Range	Mean	Std
LS	2003	186,276	72	342	270	196	56
LS	2060	163,692	69	326	257	187	53
PB	2003	54,074	66	229	163	148	40
PB	2060	42,862	64	218	154	137	38

Std, Standard deviation

Table 2-9. Carbon storage in the four pools (Mg) for the Lower Suwannee River (LS) and Pensacola Bay (PB) watersheds, Florida

Watershed	Aboveground	Belowground	Soil	Dead	Total	p
LS-2003	10,193,638 (27.86%)	2,056,594 (5.62%)	21,136,310 (57.77%)	3,200,208 (8.75%)	36,586,750 (100%)	0.0005
LS-2060	8,467,580 (27.64%)	1,697,010 (5.54%)	17,848,700 (58.26%)	2,624,870 (8.57%)	30,638,160 (100%)	
PB-2003	1,396,430 (17.46%)	280,855 (3.51%)	5,504,360 (68.82%)	816,620 (10.21%)	7,998,265 (100%)	0.0009
PB-2060	1,015,730 (17.31%)	191,896 (3.27%)	4,040,830 (68.88%)	618,348 (10.54%)	5,866,804 (100%)	

$p<0.05$, significant differences

Table 2-10. Timber volume values for the Lower Suwannee (LS) and Pensacola Bay (PB) watersheds, year 2003-2060

Watershed	Timber volume	Area (ha)	Mean*	Std*	Total**	p
LS	Volnet 2003	186,276	109.53	66.22	20,402,395	0.0005
LS	Volnet 2060	163,692	110.58	67.92	18,100,416	
LS	Volsaw 2003	186,276	83.09	72.83	15,477,193	
LS	Volsaw 2060	163,692	82.72	72.33	13,540,937	
PB	Volnet 2003	54,074	68.60	54.95	3,709,552	0.0044
PB	Volnet 2060	42,862	68.34	57.75	2,929,327	
PB	Volsaw 2003	54,074	54.80	40.96	2,963,514	
PB	Volsaw 2060	42,862	53.87	43.54	2,309,049	

* in cubic meter per hectare; ** in cubic meter; Std: standard deviation; Volnet: net volume; volsaw: volume in the sawlog portion; $p<0.05$, significant differences

Table 2-11. Water yield for the Lower Suwannee (LS) and Pensacola Bay (PB) watersheds

Watershed	Year	Mean*	Mean Total volume**	p
LS	2003	1,293	93,193,344	0.002
LS	2060	1,342	96,694,988	
PB	2003	1,520	104,635,694	0.0412
PB	2060	1,577	108,440,687	

* in mm; ** in m^3; $p<0.05$, significant differences

Table 2-12. Average volume in m3 for the Gopher gage station and the InVEST water yield model

Year	Volume at gage station	Volume water yield model	Difference
2000	4,052,867,141	4,340,245,073	-287,377,932
2001	4,667,723,281	4,591,129,229	76,594,052
2002	3,181,523,048	5,674,599,116	-2,493,076,068
2003	10,402,507,944	6,268,311,839	4,134,196,105
2004	9,642,874,632	6,166,135,117	3,476,739,515
2005	12,636,723,568	5,895,177,138	6,741,546,429
2006	6,300,488,059	4,054,040,486	2,246,447,573
2007	3,637,303,035	4,367,875,584	-730,572,549
2008	5,982,335,754	5,303,463,592	678,872,162
Average	6,722,705,162	5,184,553,019	1,538,152,143

Table 2-13. Pearson Correlation coefficients between carbon storage, timber volume, water yield and percentage (%) of forest change for the Lower Suwannee River and Pensacola Bay watersheds at the sub-watershed level

		% of forest change	Carbon	Timber	Water
LS	% of forest change	1			
LS	Carbon	0.981	1		
LS	Timber	0.986	0.981	1	
LS	Water	-0.856	-0.927	-0.868	1
PB	Forest area variation	1			
PB	Carbon	0.994	1		
PB	Timber	0.974	0.966	1	
PB	Water	-0.143	-0.129	-0.201	1

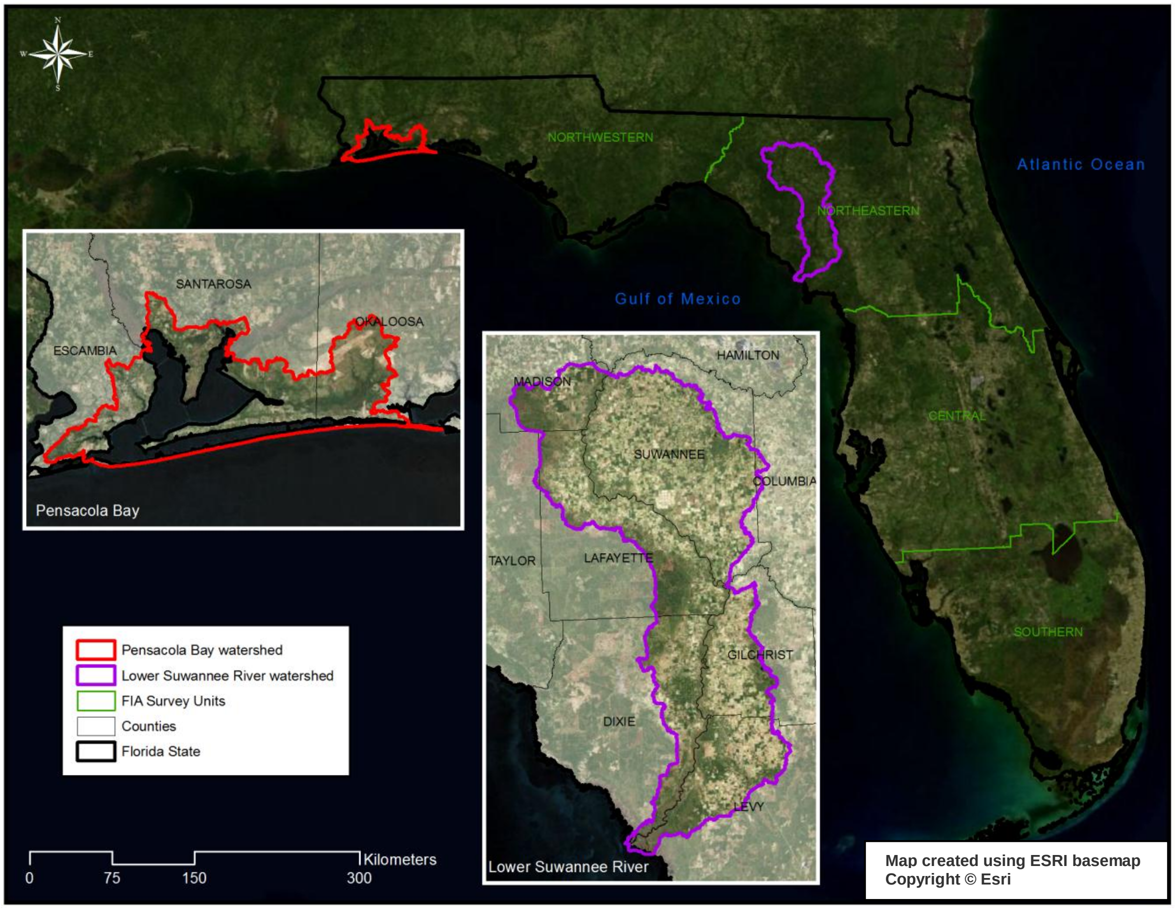


Figure 2-1. Study area: Lower Suwannee River and Pensacola Bay watersheds

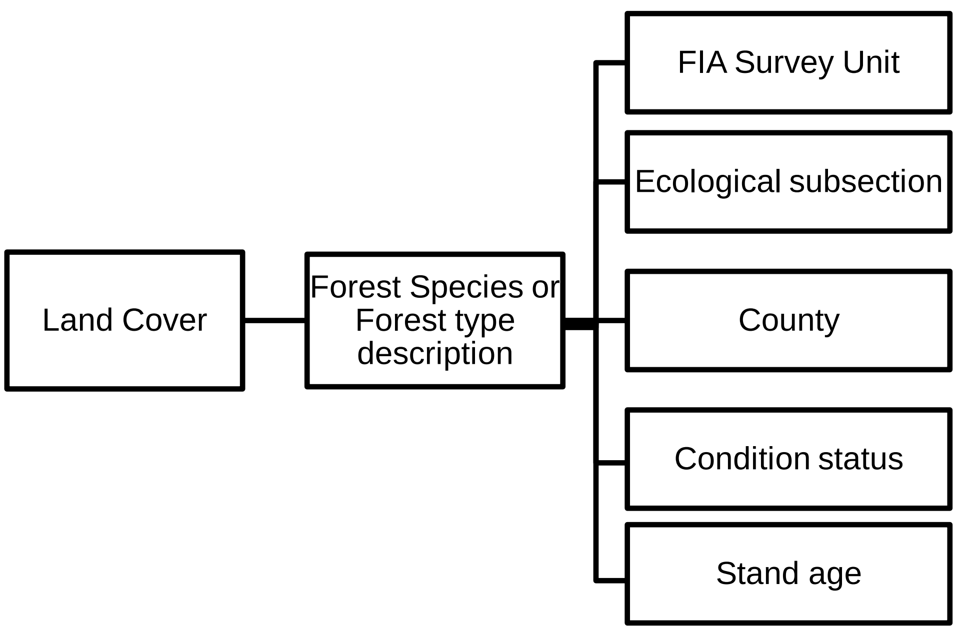


Figure 2-2. Approach for the estimation of carbon pools and timber volume using the Forest Inventory and Analysis (FIA) program data

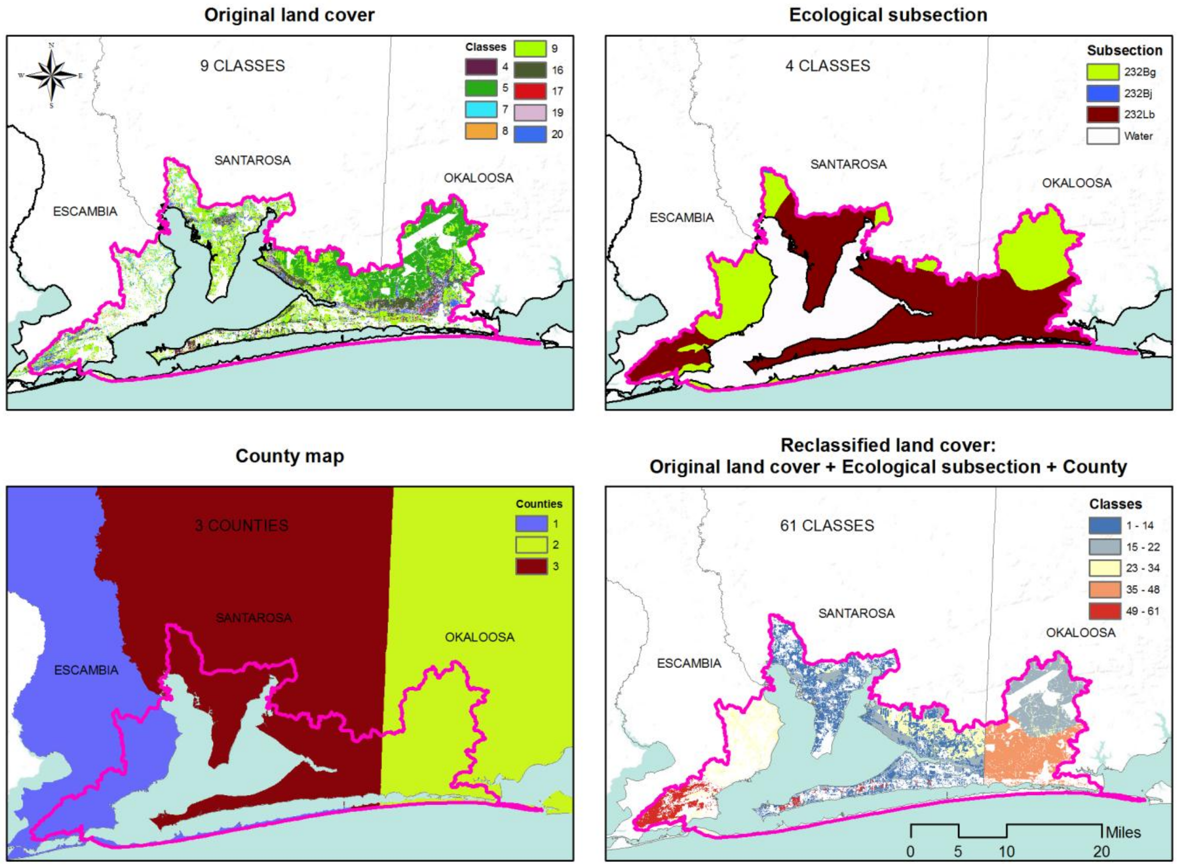


Figure 2-3. Reclassification of the original land covers to include the ecological subsection and county data.

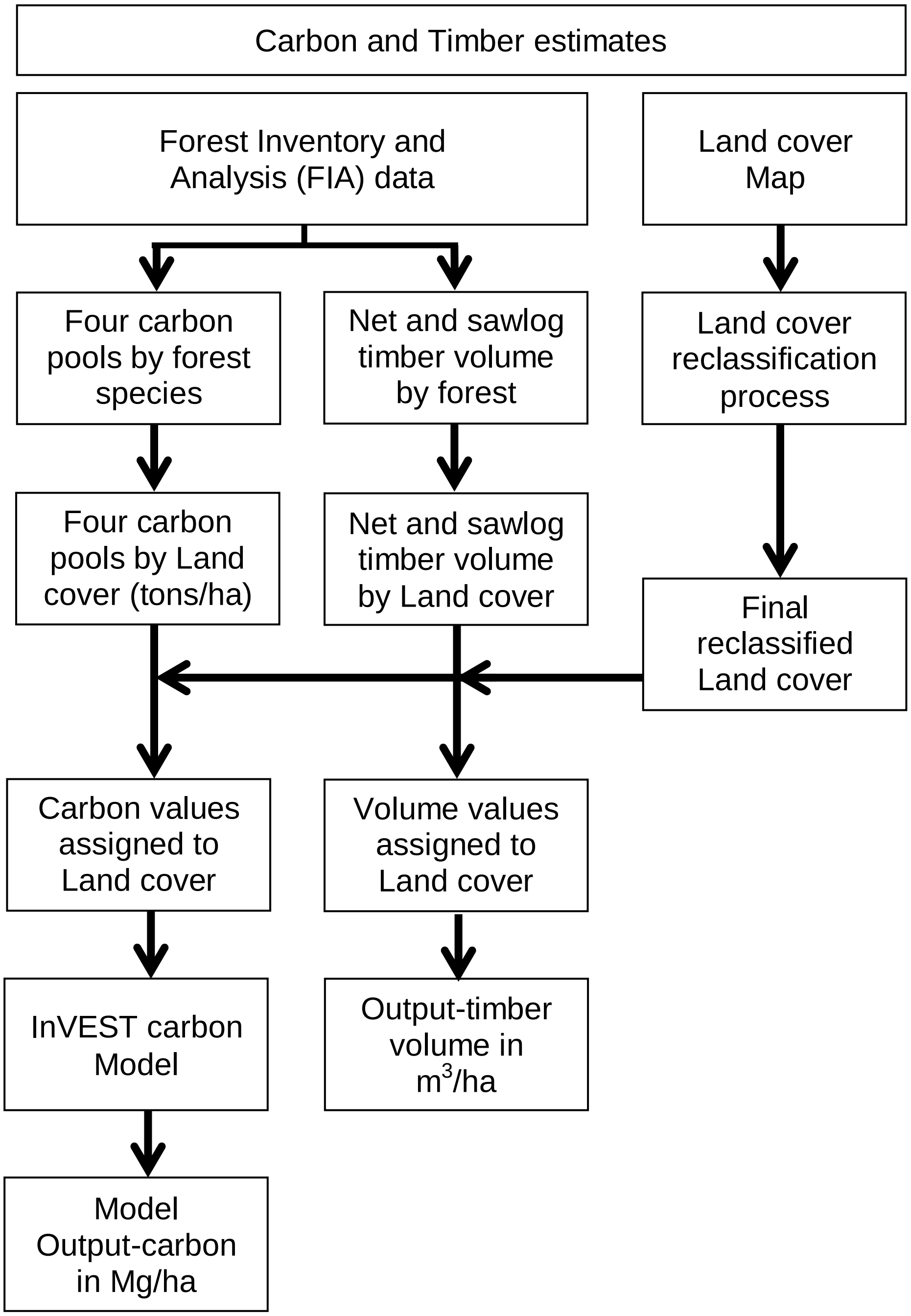


Figure 2-4. Flow chart for estimating carbon and timber in the Lower Suwannee River and Pensacola Bay Florida watersheds to approximate the exact locations of the Forest Inventory and Analysis (FIA) plots

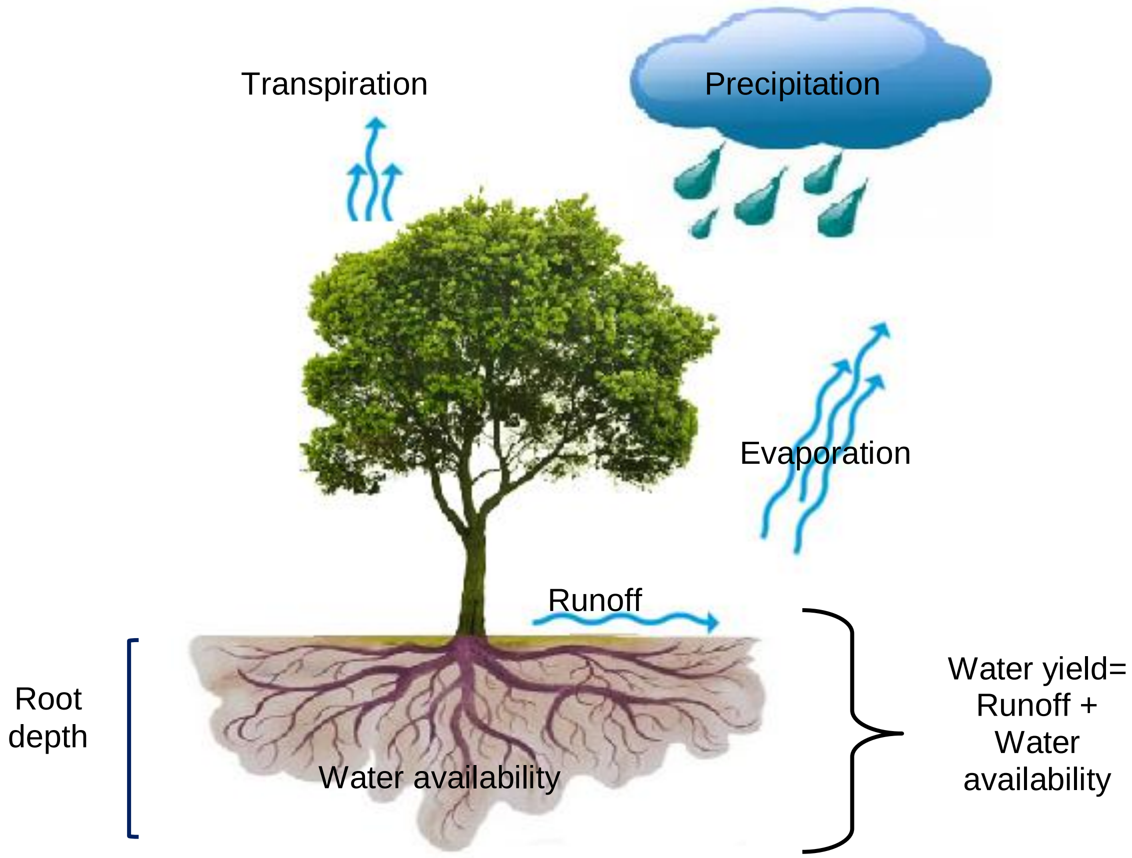


Figure 2-5. Conceptual framework for the InVEST water yield model. [Adapted from Tallis, H., Ricketts, T., Guerry, A., Wood, S., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C., Guannel, G., Papenfus, M., Toft, J., Marsik, M., and J. Bernhardt. 2011. Invest 2.2.2 User's Guide. (Page 229, Figure 1). The Natural Capital Project, Stanford.]

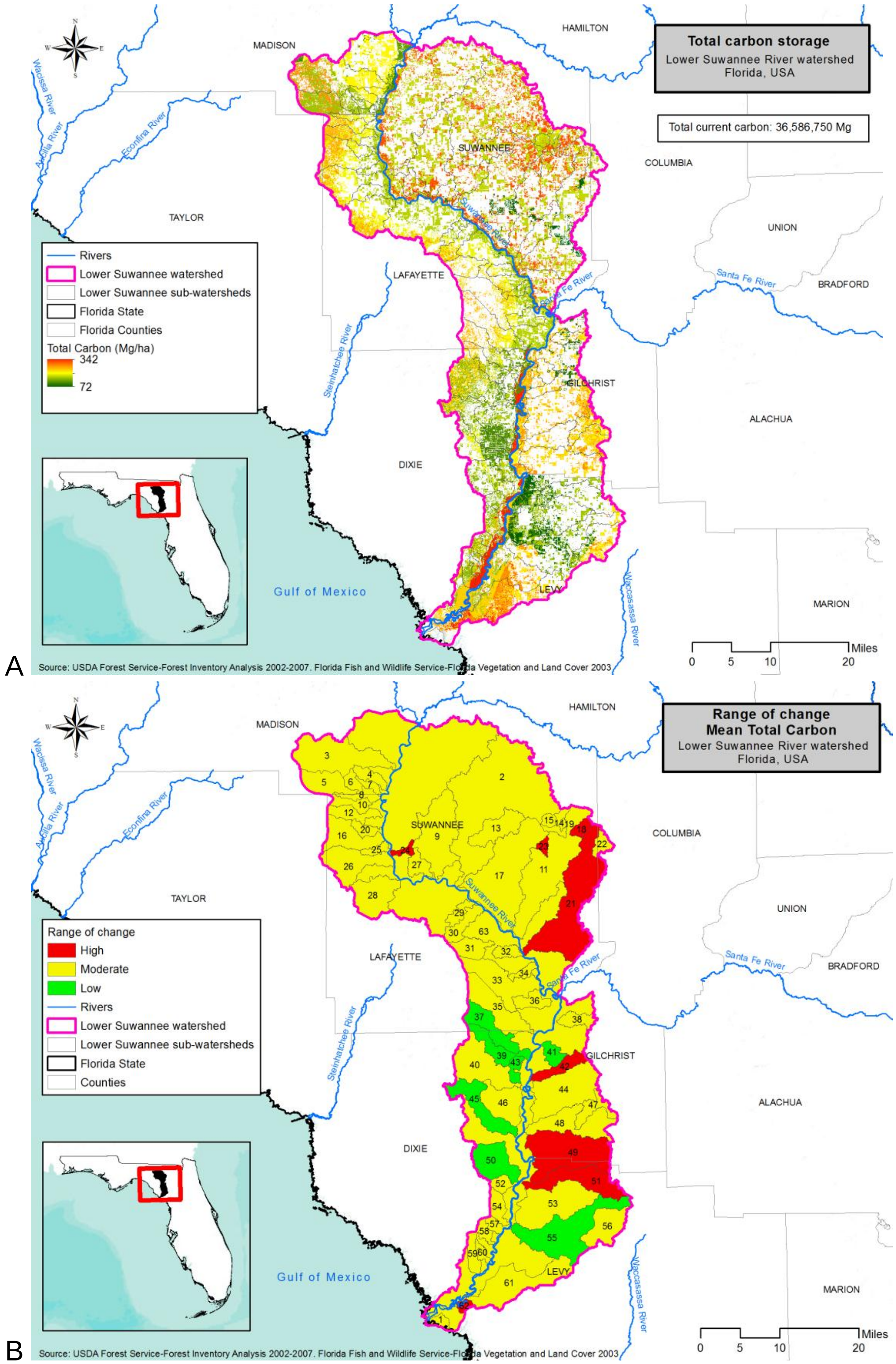


Figure 2-6. Total Carbon storage in the Lower Suwannee River, Florida. A) Total carbon storage in 2003. B) Range of change in mean total carbon between 2003 and 2060 by sub-watershed.

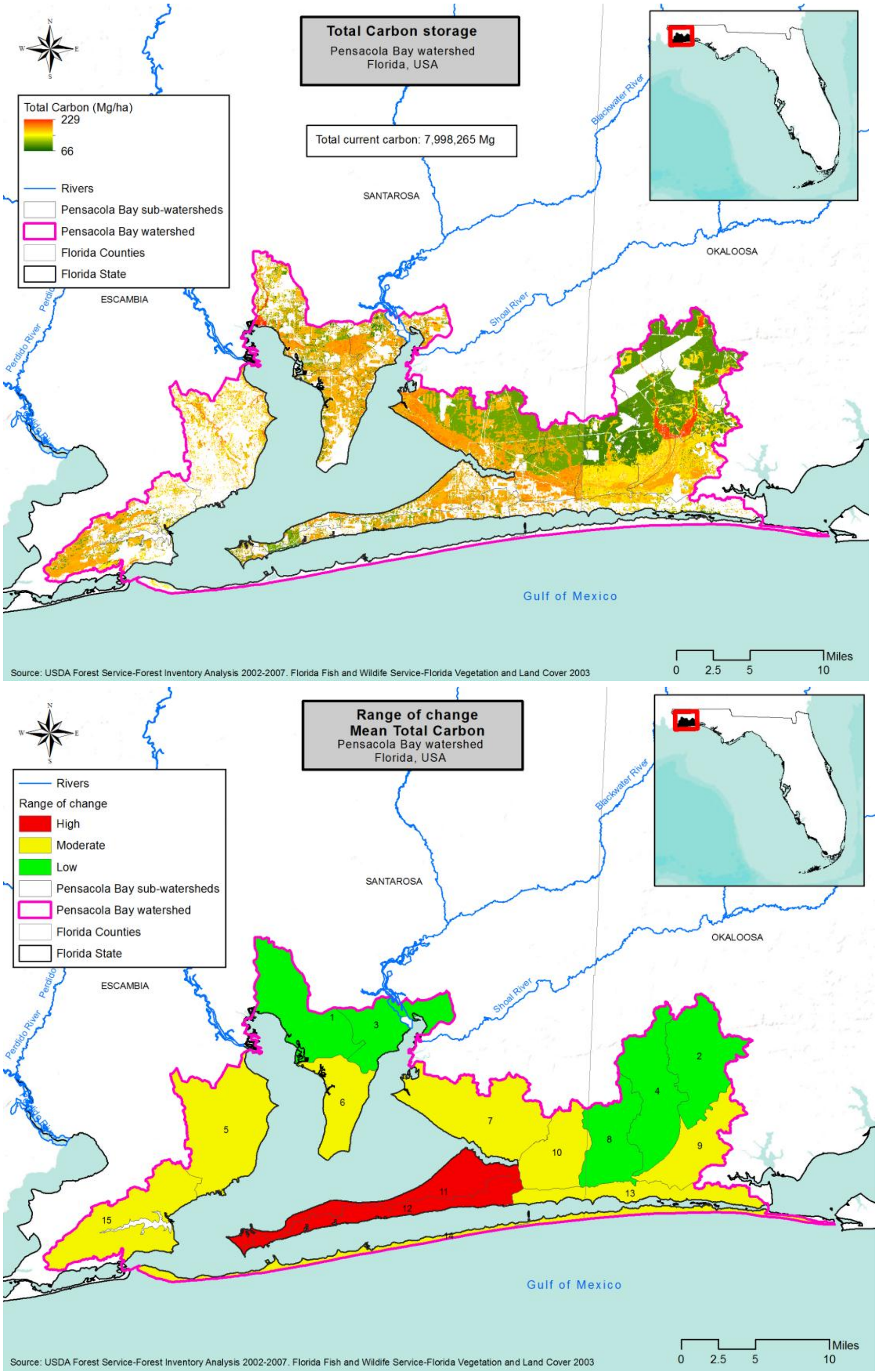
A
B


Figure 2-7. Total carbon storage in the Pensacola Bay watershed. A) Total carbon storage in 2003. B) Range of change in mean total carbon between 2003 and 2060 by sub-watershed

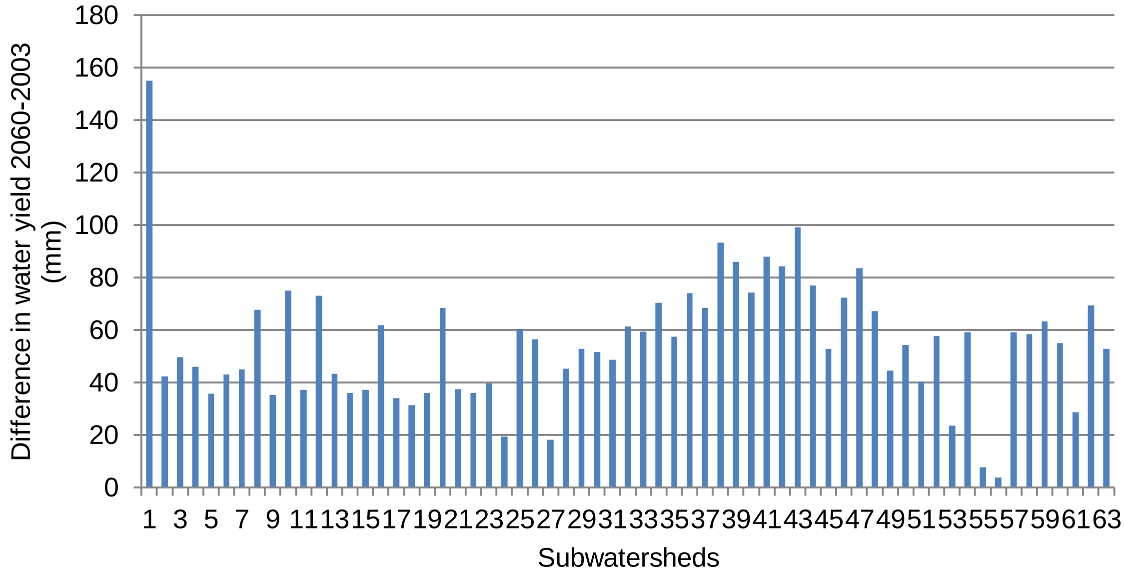


Figure 2-8. Differences between 2060 and 2003 in the water yield per hectare for the Lower Suwannee River watershed

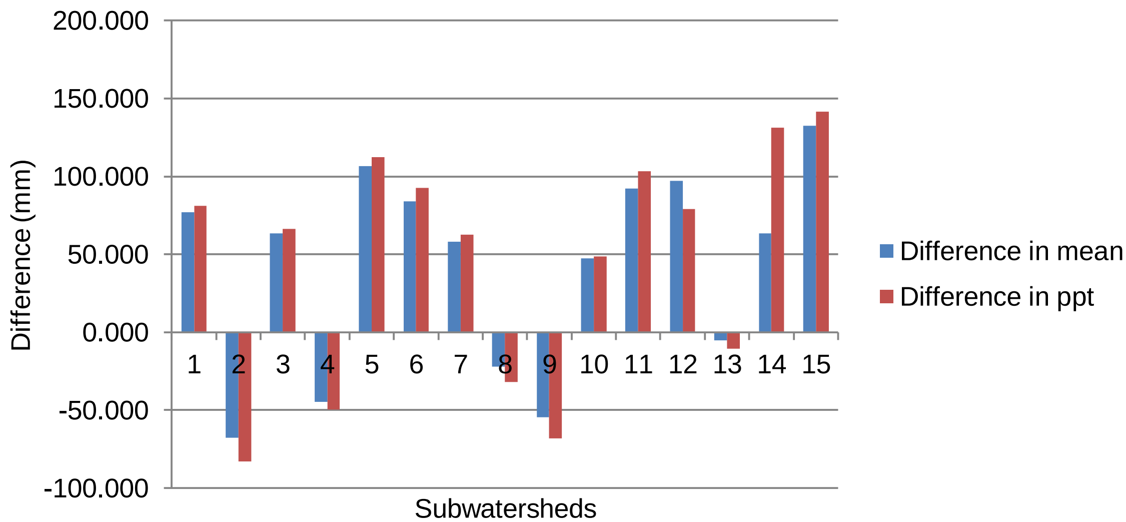


Figure 2-9. Differences between 2060 and 2003 in the water yield (mean) and precipitation (ppt) for the Pensacola Bay watershed

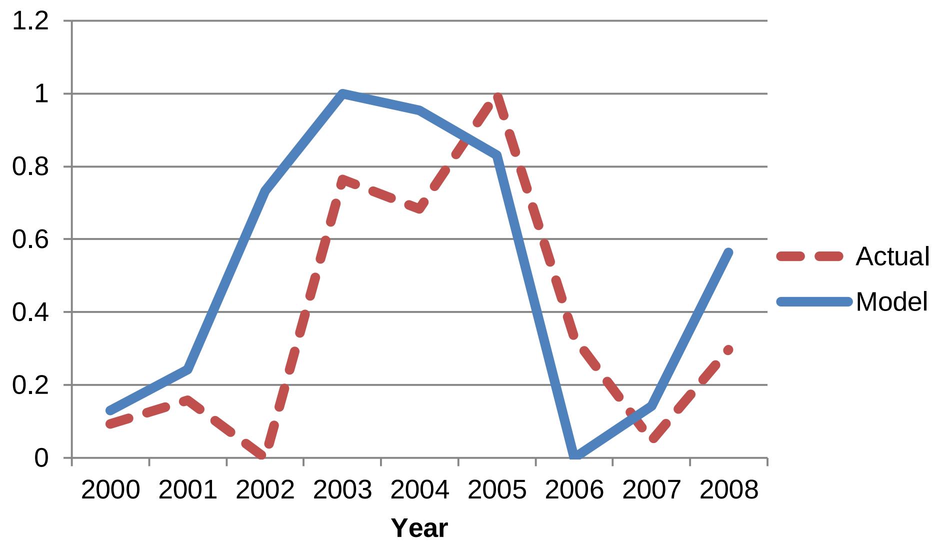


Figure 2-10. Normalized curves showing differences between average water yield volume from the InVEST model and the Gage station data (actual) for the Lower Suwannee River watershed

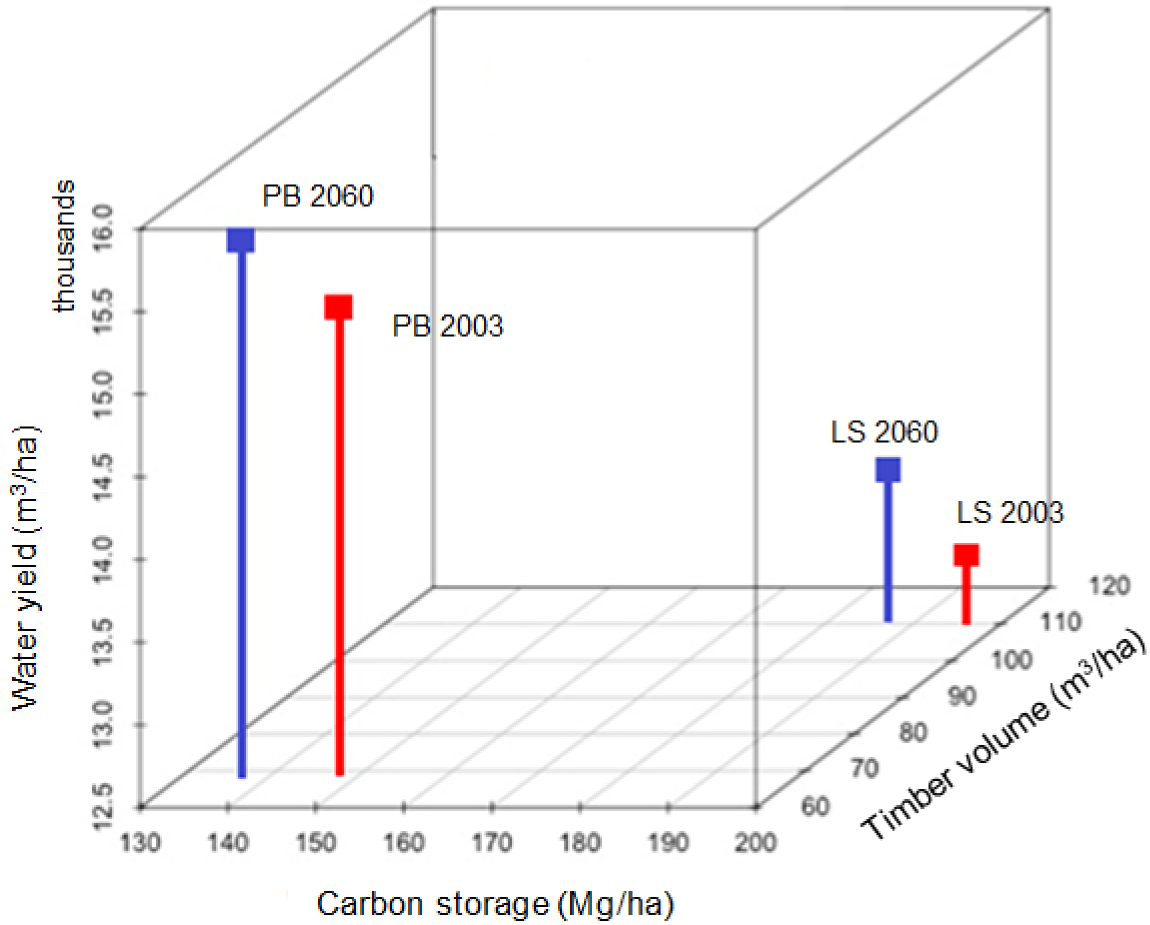


Figure 2-11. Carbon storage, timber volume, and water yield in 2003 (current) and 2060 for the Lower Suwannee (LS) and Pensacola Bay (PS) watersheds

CHAPTER 3
ASSESSING AND MAPPING POTENTIAL LOSS OF ABOVEGROUND CARBON STORAGE AND TIMBER VOLUME FROM HURRICANES

Background

Hurricanes are considered one of the major threats to forest ecosystems in the southeastern United States (U.S.) since the frequency of a major hurricane making landfall in the eastern U.S. is every 2 to 3 years (McNulty, 2002). In many cases, the quantification of forest damage is not taken into account because the damage is low compared to human lives and property losses (McNulty, 2002). However, the damage to forests can be significant and large areas of forest ecosystems can be altered, as well as their functions and services; consequently affecting human well-being (Kupfer et al., 2008; Wear and Greis, 2002b). Predicting the impacts of hurricanes on ecosystems then becomes important in terms of the development of strategies for management, post-hurricane response and restoration, salvage logging potential, and especially for long-term ecosystem analyses (Kupfer et al., 2008).

According to Hanson (2010), hurricanes, tornadoes and other natural disturbances create periodic forest clearings. One example is Hurricane Katrina, a category 5 in the Saffir-Simpson Hurricane wind scale, that produced an estimated loss of 320 million trees in Louisiana and Mississippi in 2005 (Hanson et al., 2010). Florida is one of the most vulnerable areas to hurricanes (Leatherman and Defraene, 2006), and climate change projections suggest that hurricanes will increase in frequency as well as intensity in the next years (Stanton and Ackerman, 2007). According to Stanturf et al. (2007) in the southern U.S., the probability of having a hurricane event is greater over the next 40 years. This situation generates the need to better understand how a forest ecosystem's structure and its services can be altered as a result of this disturbance. As such, hurricanes are considered an ecological driver affecting ecosystems since by definition drivers are ecological or human factors that can affect ecosystem composition, functioning, and processes, increasing or decreasing the provisioning of ecosystem services (Hanson et al., 2010; Millennium Ecosystem Assessment, 2003).

Impacts of Hurricanes on Forests and Ecosystem Services

Hurricanes can affect forests by creating fragmentation, as well as different stand ages and successional stages (Foster and Boose, 1992). Myers et al. (1998) mentioned that severe hurricanes (e.g. Hurricanes Camille in 1969, David in 1979, and Gilbert in 1988) caused forest mortality and forest canopy loss of up to 100%. Brokaw and Walker (1991) mentioned defoliation, uprooting, and snapping as the principal types of damage to forest due to hurricanes. Moreover, this effects of forest structure can influence ecosystem services such as the ability of a forest to store and sequester carbon, especially in terms of short-term carbon storage (McNulty, 2002; Uriarte and Papaik, 2007; Worley, 2008). For example, hurricanes can reduce the amount of carbon stored in the aboveground portions of trees; according to McNulty (2002) the 10% of the total annual carbon sequestered in U.S. forests is converted to dead wood due to hurricanes. For hurricane Katrina, 20% of annual forest carbon sequestration was lost, corresponding to 40 million metric tons of forest carbon (McNulty, 2002; Worley, 2008).

However, not all the carbon is released into the atmosphere; carbon is transferred from the living to dead pool, as well as to the soil pool after some period of time (McNulty, 2002; Myers and van Lear, 1998). Frangi and Lugo (1991) found that after Hurricane Hugo impacted a flood plain forest in Luquillo Mountains of Puerto Rico, ten percent of the aboveground biomass was transferred to the forest floor. Tanner et al. (1991) mentioned that after Hurricane Hugo, the total litter generated by the hurricane was equivalent to two years of litter fall. Besides the conversion of biomass from live to dead pool, Chambers et al. (2007) also mentioned the shift from larger tree sizes to smaller ones, thus resulting in lower biomass.

To evaluate if hurricanes can have either positive or negative consequences on ecosystem services such as carbon storage several factors need to be analyzed such as the amount of carbon that is converted from living wood to dead wood, as well as how much is released to the atmosphere (McNulty, 2002). The amount of wood that can be salvaged determines how much carbon is lost by hurricanes. For example, McNulty (2002) mentioned that after Hurricane Hugo in 1989 only 13% of the timber was salvaged representing an amount of less than 9% of the carbon storage. Because a forest requires approximately 15-20 years to recover after a hurricane, a large amount of carbon can be lost (Lugo, 2008; McNulty, 2002). On the other hand, hurricanes can eliminate older trees, thus favoring the establishment of younger trees, and in doing so, the amount of carbon sequestered can increase because younger trees have more photosynthetic activity (McNulty, 2002). The loss in timber volume is also important, since hurricanes can generate huge financial losses. Stanturf et al. (2008) mentioned that the estimated loss in economic terms due to hurricane Katrina was about $1.4 to $2.4 billion and Jacobs (2007) estimated that the potential loss in forest volume due to Charley, Frances, Ivan, and Jeanne hurricanes was about 56,000,000 cubic meter of timber.

Tanner et al. (1991) discussed some effects of hurricanes on forests' ecosystem processes such as the reduction in the forest area that will also reduce evapotranspiration after a hurricane impact. They also mentioned that the nutrient cycling is altered because of all the litter and downed biomass added to the soil. Some authors mentioned that hurricanes can increase the risk of secondary damages. The increase in forest fuels, especially when some dry conditions occur, increases the probability of wildfires occurrence with the potential to release carbon into the atmosphere (Dale et al., 1998; Lugo, 2008; McNulty, 2002; Myers and van Lear, 1998; Uriarte and Papaik, 2007). With high levels of rainfall the soil can be saturated producing a risk of flooding and erosion (Tanner et al., 1991). Other consequences of hurricanes are the increase in disease risk (Lugo, 2008; McNulty, 2002) and the invasion of some species, increasing the risk of the extinction of other species (Lugo, 2008). Horvitz et al. (1998) studied forest areas impacted by Hurricane Andrew in Florida and found that in terms of forest species regeneration, after the hurricane 28% of 90 species identified were invasive.

Factors Controlling Hurricane Damage on Forests

The pattern of hurricane damage on forests is the result of the combination of meteorological, physiographic, biotic (Duryea et al., 2007; Foster and Boose, 1992; Oswalt and Oswalt, 2008), historical (e.g. previous natural disturbance) and stochastic processes (Foster and Boose, 1992; Myers and van Lear, 1998). Myers et al. (2008) mentioned that the cumulative effects of hurricanes alter forest structure and composition in the long term. The relationship between wind speed and duration with forest damage is not however clearly understood (Boose et al., 1994). Studies mention that the most important factor that determine a forest’s vulnerability to hurricane damage are stand characteristics such as tree diameter, height, age and species (Merry et al., 2010; Xi et al., 2008). In the particular case of Hurricane Katrina, damage to forests was more related to stand conditions and site characteristics (Kupfer et al., 2008; Oswalt and Oswalt, 2008; Stanturf et al., 2007). On the other hand, studies also mentioned that the highest damage in forests was the result of higher wind speeds (Boose et al., 1994; Duryea et al., 2007) and the distance to landfall. For example, Oswalt and Oswalt (2008) concluded that the damage to forests decreased when the distance to landfall increased, in other words, when the distance from the coastline (i.e. where hurricane reaches land) to inland areas increased.

Additionally McNulty (2002) found no evidence of forest damage from hurricanes with hurricane categories below 3. Boose et al. (1994) performed an analysis on the impacts of hurricanes on forests in Puerto Rico and concluded that the damage was strongly related with differences in elevation (below 600 m) and vegetation type (Colorado, palm, and dwarf forest types). Duryea et al. (2007) mentioned that the damage to urban trees will depend on several factors such as species, wind speed, soil type, moisture, and depth, tree health, and topography. According to Bromley (1939) soils with hard clay horizons resulted in increased susceptibility to uprooting. Regarding stand characteristics, Duryea et al. (2007) found that urban trees that grew in groups had 80% of possibility to survive after a hurricane impact, comparing to 70% for the individual, open-grown trees.

In regards to individual tree characteristics, Foster and Boose (1992) found that damages was influenced by forest height, composition, slope, and aspect. In terms of forest type, softwoods were most affected by hurricanes resulting in severe damage and hardwoods were less affected (Foster and Boose, 1992). However, Oswalt and Oswalt (2008) concluded that softwoods do not experience more damage than hardwoods. They also mentioned that there was a relationship between forest type and distance to landfall, as damage in hardwoods increase with the increase in distance to landfall. Furthermore, softwoods experienced more damage in the zone where the distance to landfall was less (generally referred to as zone 1, closer to the coastline). Kupfer et al. (2008) included several variables in their analyses of hurricanes damage that can also play an important role in the determination of the patterns of damage in forests such as: wind speed, rainfall, topography, and floodplain conditions (e.g. soil) and found that hurricane damage was a combination of several of these factors or variables.

Assessing and Mapping Hurricane Damage in Forests

A combination of field, remote sensing, climate (Boose et al., 1994; Kupfer et al., 2008; Oswalt and Oswalt, 2008), and historical data (Boose et al., 1994) are necessary to better estimate forest damage by hurricanes. Kupfer et al. (2008) for example used aerial photographs for forest damage analysis, as well as rainfall data, wind speed, duration of hurricane, and wind direction, and the overall accuracy using a classification tree analysis was 71.5%. Jacobs (2007) developed a rapid response method for assessing hurricanes potential damage in forests based on the delineation of the damage areas using the hurricane track, wind speed, wind patterns, rainfall accumulation, and tidal surge areas, and forest damage based on U.S Department of Agriculture Forest Inventory and Analysis (FIA) data. Jacobs (2007) mentioned that most of the forest damage is observed immediately adjacent to the windward side of the track. Further, Oswalt and Oswalt (2008) estimated the forest damage by hurricanes based on FIA data and the damage zones outlined by Jacobs (2007).

Wang and Xu (2010) performed a comparison of different vegetation indices techniques (e.g. Normalized Difference Vegetation Index-NDVI) from pre and post-hurricane using Landsat 5 TM imagery and aerial photos to identify damaged forests due to hurricane Katrina using the supervised classification method. Based on an error matrix to assess accuracy, results showed an overall accuracy ranging from 51% to 86%. Chambers et al. (2007) quantified the carbon loss by Hurricane Katrina using detailed field data (i.e. FIA), remote sensing analyses, and a model to estimate forest damage. Wang and Xu (2009) applied Geographic Information System (GIS) and logit regression to assess the influence of several factors (i.e. forest characteristics and site conditions) on pattern, severity and probability of damage due to hurricane Katrina.

Other studies have used decision-tree analyses to assess hurricanes. Decision tree is an analytic method that can be used to select between different options or choices considering high or low risk, cost, or influence using a graphic approach to compare different alternatives (Olivas, 2007). However, the decision comprises some uncertainty. Li et al. (2009) applied a decision-tree analysis and a set of decision rules to find the influence of four parameters: sea surface temperature, vertical wind shear, atmospheric water vapor, and zonal stretching deformation on tropical cyclone formation and intensity. Kupfer et al. (2008) also used a classification tree analysis to develop models for Hurricane Katrina based on storm meteorology, stand conditions, and site characteristics to predict forest damage. Howard et al. (1972) applied a decision-tree analysis to make the decision of seeding, or not, a hurricane to reduce its intensity. DeLoach and Dicke (2005) presented several questions for landowners that involve timber salvaged and management decisions and developed a Timber Stand Salvage Decision Model to determine salvaging of damaged timber.

However, few studies that have assessed the potential role of hurricanes as direct drivers of forest ecosystem services such as carbon storage and timber. Furthermore, there are few hurricane-related studies that identify and map high and low forest damage risk zones that can then be used to predict possible damages or conversely identify areas where pre-hurricane management practices can be used to reduce hurricane damage to forests. Dale et al. (2008) mentioned to the possibility of managing forests to alter their vulnerability to hurricanes, by the selection of forest species, silvicultural techniques (e.g. thinning), and genetic engineering. Post-hurricane forest management includes debris and downed tree clean-up to avoid other events such as wildfires and diseases resulting from the accumulation of biomass in the forest (Myers and van Lear, 1998). However, this kind of information is not available for Florida.

Therefore, this study will develop a framework based on a decision-tree analysis that can be used for assessing forest damages due to hurricanes with available field data. This information can also be used to help land managers understand the consequences of hurricanes on their forests in terms of loss of ecosystem services, as well as to predict the responses of ecosystems, and forest/emergency management activities, to this kind of disturbances (Dale et al., 1998; Kupfer et al., 2008). Decision-tree analysis can also be useful for determining areas with high probability of timber salvaged after a hurricane. By knowing this information managers can be prepared for such events taking into account in their management plans, and consequently they can reduce losses to forests, property, and ecosystem services (Kupfer et al., 2008).

In this chapter, the risk of forest damage by hurricane was assessed and mapped. Specifically, this study's objective was to determine potential loss of ecosystem services in terms of aboveground carbon storage and timber volume that can be affected by a direct driver – hurricanes. Another objective was to develop a decision-tree analysis framework to identify zones of high and low forest damage risk by hurricanes using existing literature and available plot-level spatial data such as: tree diameter and height, type of species (e.g. softwoods and hardwoods), basal area, and distance to landfall (damage zone).

Methods

Study Areas

The highly forested Lower Suwannee River watershed in west Florida and the more urbanized Pensacola Bay located in Northwestern Florida were selected for this study (Figure 2-1; Table 2-1).The Lower Suwannee watershed consists of an area of 408,828 ha, and is one of five watersheds that comprise the Suwannee River watershed (Katz et al., 1997). Eight counties are within the watershed boundary: Columbia, Dixie, Gilchrist, Lafayette, Levy, Madison, Suwannee, and Taylor. The Suwannee river is the second largest river in Florida in terms of average discharge (Light et al., 2002). Several studies were done in the Lower Suwannee watershed due to the threat of the transition from natural ecosystems to more intense land-use practices (Martin, 2007) and the area has been defined by Obreza and Means (2006) as one with unique biota and water resources that need to be protected.

The Suwannee watershed is also characterized by the presence of karst features, wetlands, lowland topography, and a small number of tributary streams (Katz et al., 1997). Interactions between groundwater and surface water occur within the Suwannee River watershed due to the presence of karst features. The land cover type in the watershed is predominantly forest, agriculture, and wetlands (Katz et al., 1997) and has 63 sub-watersheds. The watershed has subtropical weather with warm summers and moderate winters (Katz et al., 1997). The average precipitation in the watershed is

1,270 mm per year (Obreza and Means, 2006). The Lower Suwannee River watershed was affected by several hurricanes. According to Light et al. (2002), the hurricanes impacting the watershed were: Alma (1966), Agnes (1972), Josephine (1996), Earl (1998), Opal (1995), and Georges (1998).

The Pensacola Bay watershed comprises an area of 140,825 ha and is part of the Pensacola Bay system that is composed by five watersheds (Schwenning et al., 2007). The counties of Escambia, Okaloosa, and Santa Rosa are within the watershed boundaries. This watershed includes the Pensacola Bay estuary and parts of four major rivers: Escambia, Blackwater, Shoal and Yellow Rivers, and some small tributaries (Florida Department of Environmental Protection, 2007; Thorpe et al., 1997). The watershed was chosen because of its different land cover characteristics compared to the Lower Suwannee River watershed. The Pensacola Bay watershed is more urbanized than the Lower Suwannee with around 30% of its area covered by urban areas.

The Pensacola Bay system has unique features such as its morphology and the hydrodynamics that are considered key points for the natural ecosystems. However, over the last decades it was impacted by human activities such as habitat damage, urban development, and point and non-point source pollution such as industrial and domestic waste and non-point source pollutants from urban, suburban, and agricultural areas (Thorpe et al., 1997; U.S. Environmental Protection Agency, 2004). Natural ecosystems such as wetlands and aquatic habitats have been affected by urban related deposition and sedimentation (Thorpe et al., 1997), as well as through conversion and fragmentation (Northwest Florida Water Management District, 2006). The Pensacola

Bay watershed has a humid subtropical weather and annual precipitation ranges from 730 to 2,280 mm (Hays, 2009) with an average of 1,625 mm (Thorpe et al., 1997). Pensacola Bay is affected by hurricanes approximately every five to ten years (NOAA-National Hurricane Center, 2012a). The last major hurricanes in the area were Ivan in 2004 and Dennis in 2005 (Hays, 2009). According to NOAA-National Hurricane Center (2012a), the hurricanes that affected Pensacola Bay watershed were: Eloise(1975), Fredrick (1979), Elena (1985), and Opal (1995).

Quantification of Aboveground Carbon Storage and Timber Volume

Aboveground carbon storage and timber volume were estimated using the USDA Forest Inventory and Analysis (FIA) data and the Florida Vegetation and Land Cover 2003 (Florida Fish and Wildlife Conservation Commission, 2004). Both data sets were input into the InVEST model, developed for the Natural Capital Project to analyzing the amount of aboveground carbon storage (Natural Capital Project, 2011).

Forest Inventory and Analysis Program Data

The USDA Forest Service Inventory and Analysis (FIA) program data was used for analyzing forest carbon storage. Several studies (Jenkins et al., 2003; Smith et al., 2004; Woodbury et al., 2007) have used this database for calculating forest carbon stocks. The FIA data set contains database for the forest lands in all the U.S including forest characteristics, such as extent, condition, and volume. The FIA Program started in 1929 with periodic forest inventories of nation-wide network of plots in all the U.S. and since 1999, these inventories are conducted annually (Jenkins et al., 2003; Woudenberg et al., 2010). The plot-level data is based on individual tree measurement.

One limitation with the FIA data is that exact geographic coordinates (latitude and longitude) of the plots are not provided because of the “Privacy provision” enacted by

Congress in the Food Security Act of 1985 to ensure private landowners' privacy and plot integrity. The location of the plots is approximately with a buffer of 1 mile or ½ mile from the exact position. Moreover, 20% of the plots are swapped, which means that some private plots are exchanged with other similar private plot, in the same county (Woudenberg et al., 2010). This situation creates an uncertainty while plots need to be overlaid with other GIS data. Sabor et al. (2007) found that the potential error of using the altered location of the plots in combination with other layers, for example for a 30 meters by 30 meter raster layers, plot misclassification ranged from 32% to 66%. However, different approaches, based on other FIA attributes, can be applied to better use the data and approximate the location. For example, only the 1-10 % of plots were misclassified using ecological subsection data (Sabor et al., 2007).To deal with the problem of the precise FIA plot location, a different approach can be developed to approximate the aboveground carbon and timber volume for the different forest types. Some attributes available at the FIA database used for this the FIA Survey Unit, ecological subsection, county, condition status, and stand age (Figure 2-2).

To extract the aboveground carbon and timber volume from the FIA data, the Tree table was used (Woudenberg et al., 2010), which contains individual tree data. A tree expansion factor, which can be found in the Tpa_unadj attribute in the Tree table was used to scale each tree on a plot to a per-acre basis, considering the number of trees per acre (TPA) (Woudenberg et al., 2010). Per tree values for aboveground carbon and timber volume were multiplied by the corresponding Tpa_unadj to get the plot-level data.

Using the Pivot table function in Microsoft Excel® (Microsoft, 2010), these values were summed by plot (PLT_CN) considering specie code (SPCD), FIA survey unit (UNITCD), ecological subsection (ECOSUBCD), county (COUNTYCD), condition status (COND_STATUS_CD), and stand age (STDAGE). The aboveground carbon and timber volume for each plot was calculated. Then, the average was calculated using these plot data to get the value for each species, considering the ecological subsection and county. To assign the aboveground carbon and timber volume to a raster file (i.e. reclassified land cover) from unidentified FIA plot locations, the forest species were identified in both data, so the carbon values in the FIA data for one specific forest specie, one ecological subsection, and one county were assigned to the each forest ecosystem in the raster file that corresponded to the same attributes (i.e. ecological subsection and county).

Florida Vegetation and Land Cover 2003

The 2003 Florida Vegetation and Land cover map was developed based on Landsat Enhanced Thematic Mapper satellite imagery with a 30 meter spatial resolution and had detailed distinction between different ecosystems. It contained 43 classes of vegetation and land cover, 26 being natural and semi-natural vegetation types, 16 types of disturbed lands (e.g., agriculture and urban), and a single water class (Stys et al., 2004). For the development of the hurricane framework, 11 forest cover classes were selected and these classes were reclassified into two main tree types for analyses: softwoods and hardwoods (Table 2-1). Urban forests (i.e. all trees and other associated resources within urban areas), were not considered in the analysis.

Decision-tree Framework

Forest damage risk by hurricanes in this study considered the following as the main factors behind forest damage: tree diameter, height, basal area, tree type (softwoods and hardwoods), and distance to landfall (Merry et al., 2010; Oswalt and Oswalt, 2008; Xi et al., 2008). The reclassified land cover and main factors were combined to develop a forest ecosystem map to identified forest damage risk zones.

The tree diameter and height, as well as the basal area, and type of species (e.g. softwoods and hardwoods) were extracted from the FIA database. Mean values for each ecological subsection and county were calculated for diameter, height, and basal area considering softwoods or hardwoods. The mean tree diameter and the mean tree height were extracted from the Tree table that contains per tree level data; however the mean basal area and the tree type (e.g. softwoods and hardwoods) were extracted from the Condition table that contain per plot level data. The FIA data corresponded to cycle 8 (2002-2007) were used in the analysis because the land cover corresponds to 2003.

To deal with the problem of the precise plot location, a different approach was used to extract the mean tree diameter and height, as well as the basal area from the FIA database. The FIA attributes considered to identify the plots that are within the boundaries of the study area were: FIA Survey Unit, ecological subsection (U.S.D.A Forest Service, ECOMAP Team, 2007), county, condition status, and stand age. The FIA survey, the ecological subsection, and the county were used to approximate the location of the plots. However, the condition status and stand age were used to define the characteristics of the forests. Only plots in the study area with the condition status defined as “forest land” and with a stand age ranging from 1 to 72 years were considered in the analysis. The description of each attribute is shown in Table 3-1.

The FORTYPCD attribute from the Condition table in the FIA database was used to classify the tree type in the database and to better extract the information and assign to the previously created raster file. The basal area of live trees on the plot (BALIVE) was also extracted from the condition table and information was added to the Tree table that contains tree diameter (DIA) and total height (HT) (Woudenberg et al., 2010). The average values for DIA, HT, and BALIVE according to tree type, plus ecological subsection and county were then calculated. The DIA, HT and BALIVE were classified in two categories: small and large, short and tall, and low and high, respectively (Table 3-2). This classification was done using the ArcGIS® 10 software and the Natural breaks (i.e. Jenks) method. The natural breaks are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes (ESRI, 2011b).

The distance to landfall, defined as the intersection of the surface center of hurricane with a coastline (NOAA-National Hurricane Center, 2012b), was used for determining the two forest hurricane damage zone as: high and moderate-low. Specifically, using the American Society Civil Engineer's Standard 7 for the 1998 (ASCE 7-98), the wind damage zones were determined according to distance to hurricane landfall (Peacock et al., 2005). The ASCE 7-98 shows a Florida map of wind risk assessment associated with hurricanes where the maximum wind speed for a given area is expected to affect building construction standards (Figure 3-2). The ASCE 7-98 was used because it presents the average worst case situation, in terms of the maximum wind speed that can affect a specific area in Florida. This map can therefore be used to delineate different hurricane damage zones by taking into account these worst case wind speeds.

For the study area, two areas of damage were identified based on the ASCE 7-98. One area had a shorter distance to landfall and a high wind speed: 13 miles of distance and 120 miles per hour for the Lower Suwannee, and 2 miles of distance and 140 miles per hour for Pensacola Bay; this area was identified as high hurricane damage zone (zone 1). The farther area and lower wind speed was identified as Moderate-Low hurricane damage zone (zone 2) and had a distance ranging from 13 to 65 miles and a wind speed of 100-110 miles per hour for the Lower Suwannee and for Pensacola Bay with a distance from 2 to 23 miles with 130 miles per hour of wind speed. The two-class vegetation map (softwoods and hardwoods) was then combined with the Ecological subsection and county raster files, as well as with the hurricane damage zones based on the ASCE 7-98.

The result of this analysis was one raster file showing the unique combination of classes for each type of forest ecosystem: hardwoods or softwoods, ecological subsection, county and hurricane damage zone. The final raster used to develop the risk of forest damage due to hurricanes in the decision tree analysis contained: 1) Tree type: Hardwood or Softwood, 2) Hurricane damage zone: high (zone 1) and moderate or low (zone 2), 3) Ecological subsection, 4) County, 5) FIA Survey Unit, 6) Mean diameter: small (code = 2) and large (code = 1), 7) Mean total height: short (code = 2) and tall (code = 1), and 8) Basal area: high (code = 1) and low (code = 2).

A decision tree scenario was developed to identify areas with high and low risk of forest damage from hurricanes (Figure 3-1) based on information presented in Oswalt and Oswalt (2008), Stanturf et al. (2007), Merry et al. (2010), Xi et al. (2008), and Kupfer et al. (2008). Forest damage, for the purpose of this study, is some degree of alteration of forests (i.e. plot- level, individual tree level). According to Oswalt and Oswalt (2008), the hardwoods are more affected by hurricanes when the distance to landfall increase (i.e. zone 2), and softwoods are more affected when they are closer to the coast (i.e. zone 1). For tree diameter, Oswalt and Oswalt (2008) report that when the diameter is smaller in softwoods and larger in hardwoods they were more affected due to hurricanes. In terms of total height when both softwoods and hardwoods are taller they are most affected by hurricanes. For basal area, both softwoods and hardwoods are more affected when the basal area is lower (i.e. low density) (Duryea et al., 2007; Escobedo et al., 2009b; Oswalt and Oswalt, 2008). Specific size, height, and density criteria and respective units are provided in Table 3-2.

Based on this information and using the final raster containing all the decision tree factors previously described, the high and low forest damage risk zones were selected using the Conditional Function in ArcGIS® Spatial Analyst. The conditional function allows the selection of several attributes from a raster file. By doing so, the areas with high and low forest damage risk zones can be identified based on the five factors analyzed. The expression used in the conditional function can be found in Table 3-3. In zone 1 (high damage) the most affected type of tree species was softwoods, with: smaller diameters (code = 2), great heights (code = 1), and lower densities (code = 2). However, in zone 2 (moderate or low damage) the most affected were hardwoods with larger diameter (1), greater heights (1), and lower densities (Oswalt and Oswalt, 2008). A map showing the high and low forest damage risk zones due to hurricanes was created for each watershed and the flow chart for the decision tree analysis is shown in Figure 3-3. A sub-watershed analysis was also done to identify the sub-watersheds with high percentage of high forest damage risk zones. Therefore, based on the total forest area of each sub-watershed, the percentage of area in both high and low forest damage risk zones was calculated.

Potential Loss of Aboveground Carbon Storage and Timber Volume

Using the aboveground carbon storage, timber net volume and timber in the sawlog portion results based on the 2003 Florida Vegetation map and the USDA FIA data (Chapter 2), aboveground carbon storage and timber volume for each zone (i.e. high and low forest damage risk) were assessed and mapped. The high-low forest damage risk map resulting from the decision tree analysis was used with the 2003-aboveground carbon storage and timber volume map to calculate the potential amount of loss of these two ecosystem services in each of these zones. Later, using the Zonal statistics as a Table in ArcGIS® Spatial Analyst, the carbon storage and timber volume raster values were summarize within each forest damage risk zone (e.g. high and low) to get total aboveground carbon storage and timber volume estimates in each zone (ESRI, 2012b).

Results

Potential Loss of Aboveground Carbon Storage Due to Hurricanes

In 2003 the aboveground carbon storage was 10,193,638 Mg for the Lower Suwannee River watershed. Considering the worst case scenario where hurricanes potentially impact all the forest areas in the watershed the approximate amount of potential loss of carbon aboveground can be up to 10,193,638 Mg. Highest average potential losses were located in the northeastern part of the watershed in the Suwannee

County (Figure 3-4). At the sub-watershed level, the current carbon aboveground ranged from 22 to 115 Mg/ha, corresponding the highest average value to Rocky Hill Tower sub-watershed that is composed by 54% of forests distributed in 38% of hardwoods and 16% of softwoods.

Table 3-4 shows the potential aboveground carbon storage for the identified high and low forest damage risk zones due to hurricanes for the Lower Suwannee River watershed. Most of the areas with high risk were located in the Northeastern part of the watershed (Figure 3-5). The area corresponding to the high risk was 23,840 ha (13%) and the low risk area was 162,435 ha (87%). The aboveground carbon in the high forest damage risk zone included 31% of the total estimated for the watershed. Considering each zone the high risk zone (zone 1) and the moderate or low risk zone (zone 2), the first one had 79,260 Mg (1%) and the second one had 3,037,890 Mg (30%). At the sub-watershed level, 22 out of 63 sub-watersheds had a high risk of experiencing some damage in their forests due to hurricanes (Figure 3-6). Rocky Hill Tower sub-watershed registered the greater high risk considering the total forest area within its boundaries that is equal to 326 hectares; or 70% of the forest has a high risk of hurricane damage and 30% of the sub-watershed’s forests are under low risk.

For the Pensacola Bay watershed, the aboveground carbon storage in 2003 was 1,396,430 Mg and ranging from 3 to 116 Mg/ha, thus, the carbon that could be potentially lost in the worst scenario was considered. High average values were located in the western part of the watershed (Figure 3-7). The sub-watershed with the highest average aboveground carbon was Bayou Texar-Bayou Garcon Frontal, with 64 Mg/ha, where 27% of the area is composed by forests, 15% being hardwoods and 12% softwoods.

About 0.3% of the existing forest area in the watershed is under high risk of damage due to hurricanes; but the rest, 99.7% are under low risk of damage. The most affected areas were located in the coastal areas of the watershed (Figure 3-8). Table 3-5 shows the aboveground carbon values in the high and low forest damage risk zones for the Pensacola Bay watershed. The aboveground carbon in the high risk zone was 0.5% of the total aboveground carbon registered in the watershed. At the sub-watershed level only 2 out of 15 sub-watersheds registered a high risk of damage based on the forest vegetation characteristics. The highest value corresponded to Fundy Bayou-Williams Creek Frontal sub-watershed with 59% of the areas defined as high risk (Figure 3-9). This sub-watershed registered only 3% of forest area. Urban areas were not assessed in this analysis.

Potential Loss of Timber Volume Due to Hurricanes

The average timber net volume (volnet) for the Lower Suwannee in 2003 was 109 m^3/ha over an area of 186,275 ha of forest, resulting in a total timber net volume of 20,402,395 m^3 approximately. Considering the worst scenario where hurricanes can damage all the forest areas, the approximate amount of volnet that can be potentially lost can be up to 20,402,395 m^3. At the sub-watershed level, the timber net volume ranged from 33 to 194 m^3/ha, with the highest average value for Gopher River sub-watershed. In this sub-watershed the 73% of the area is covered by forest where 71% corresponded to hardwoods and 2% to softwoods.

The timber volume in the sawlog portion (volsaw), in 2003 was 15,477,193 m^3 with an average of 83 m^3/ha for the Lower Suwannee River watershed. In the worst scenario where the hurricane affects all the forest areas, the approximate amount of volsaw that can be potentially lost can be around 15,477,193 m^3. Table 3-2 shows the timber net volume and the timber in the sawlog portion for the identified high and low forest damage risk zones due to hurricanes for the Lower Suwannee River watershed. The timber net volume in the high risk zones was 15% of the total observed in the watershed, and the timber sawlog portion was 32%.

For Pensacola Bay, the average timber net volume in 2003 was 69 m^3/ha in an area of 54,381 ha, the total timber net volume was approximately 3,730,642 m^3. This is the potential timber volume that can be lost in the worst hurricane scenario. At the sub-watershed level the average timber net volume ranged from 45 to 157 m^3/ha. The highest average value corresponded to Bayou Texar-Bayou Garcon Frontal where 27% of the area is covered by forests; being 15% hardwoods and 12% softwoods. The timber volume in the sawlog portion, in 2003 was 2,980,362.85 m^3 approximately with an average of 68 m^3/ha. Table 3-4 shows the values for timber net volume and timber in the sawlog portion in the Pensacola Bay watershed. The amounts of timber net volume and in the sawlog portion were low in the high risk zones: 0.7% and 0.5% of the total registered in the watershed, respectively.

Discussion

A decision tree analysis based on previous studies can help to determine the zones with high and low forest damage risk zones due to hurricanes considering the structural characteristics of forests such as tree diameter and height, as well as basal area. Results show that this method can be used to determine the effects of direct drivers on ecosystem services, specifically how aboveground carbon storage and timber volume can be potentially affected due to hurricanes in the Lower Suwannee River and Pensacola Bay watersheds.

Potential Loss of Aboveground Carbon Storage Due to Hurricanes

Hurricanes can produce a decrease in the aboveground carbon in the study area's forests. However, not all the carbon will be lost, different changes will occur in the short term as well as in the middle and long term. In the short term carbon pool changes occur as aboveground carbon in live materials shifts to carbon dead and carbon can also be stored in the salvaged timber (McNulty, 2002). According to McNulty (2002), only 15% of the total carbon can be salvaged after a major hurricane, the rest is decomposed and returned to the atmosphere in a long-term.

For the Suwannee River watershed, the area with high risk of forest damage was 13% of the total forests in the watershed, 11% being in zone 2 (moderate or low damage), where most of the forest are hardwood (87%). Oswalt and Oswalt (2008) calculated the mean percent of plot damages by hurricane Katrina and they found that 8% were damaged considering all the zones (closest and furthest from landfall). In terms of forest area damage by Hurricane Katrina, Wang and Xu (2009) found that 60% of the total forest land in the region was damaged by the Hurricane. The aboveground carbon in the high forest damage risk zone was 31% of the total estimated for the watershed, with a 30% of the amount in the zone 2 because most of the forest is located within this zone (93%).

In the Pensacola Bay watershed, the area with high forest damage risk due to hurricanes was only 0.3% of the total forest registered in the watershed. The aboveground carbon in the high risk zone was only 0.5% of the total aboveground carbon estimated for the watershed; most forest area (93%) being located within this zone. Previous studies mention that the amount of aboveground carbon that can be transferred from the living to dead pool is about 10% for a single hurricanes (McNulty, 2002), in terms of carbon emissions about 9-18% of the carbon storage can be released (Zeng et al., 2009), and for Hurricane Katrina the carbon loss was 77.6 kg per ha (Zeng et al., 2009). Apparently and according to the results of this study - the loss of aboveground carbon storage in the Pensacola Bay watershed is potentially low compared to documented losses from Hurricane Katrina; in spite the area being more affected by hurricanes because of its geographic location (i.e. ASCE 7-98 maximum wind speed for this region is 130-140 miles per hour).

Potential Loss of Timber Volume Due to Hurricanes

The timber net volume in the high forest damage risk zone was 15% and 0.7% of the total observed in the Lower Suwannee and Pensacola Bay watershed, respectively. The timber in the sawlog portion was 32% for the Lower Suwannee and 0.5% for Pensacola Bay watershed. Jacobs (2007) found that 10% of the total timber was destroyed after hurricane Camille (category 5) that impacted Southern Mississippi. Stanturf et al. (2007) mention that approximately the 20% of the standing timber volume was destroyed as consequence of Hurricane Katrina. However, McNulty (2002) mentions that across all the damage zones, 37% of the standing tree was damaged from major hurricanes such as Katrina. Jacobs (2007) mentioned that with hurricane Andrew, there was a loss in standing volume of 66% in high and moderate damage zones, with hardwoods receiving more damage. In the case of Hurricane Camille in 1969 (category 5), Jacobs (2007) produced a decrease in timber volume of 21-37%. The percentage of damage can vary significantly because of the factors that control forest damage, such as forest characteristics (Oswalt and Oswalt, 2008), regional characteristics (climate, topography) (Boose et al., 1994) and because of the uncertainty in hurricane prediction (Oswalt and Oswalt, 2008).

Some of the limitations of this study include the decision-tree analysis that was based on existing literature that identified factors controlling forest damages due to hurricanes. Thus, to get better results, this method should be used with existing pre and post-hurricane field data to be better able to determine effects based on the percentage of forest damage and to find relevant factors. Another limitation is hurricane complexity, since many factors interact to determine the degree of forest damage by hurricane, such as wind speed, rainfall, mechanical and chemical effects of storm surges, stress from hurricane-induced damage, and mortality from subsequent post-hurricane disturbances (i.e. fires), as well as the variability of forest structural characteristics and conditions(Kupfer et al., 2008).

Concluding Remarks

The main objective of this study was to determine the potential loss of aboveground carbon storage and timber volume due to drivers such as hurricanes and to identify high forest damage risk zones due to hurricanes based on the most important factors influencing forest damage. According to existing literature these factors were the tree diameter and height, the distance to landfall and the type of species that composed the forest (hardwood or softwood). Using decision tree analyses, a scenario was developed and combined with available USDA FIA and Florida vegetation and land use spatial data to better identify spatially explicit high and low forest damage risk zones in the study area. However, the uncertainty associated with hurricanes can generate highly variability resulting in uncertainty when predicting damages to forests. This uncertainty is the product of the random nature of hurricane occurrence in terms of space and time as hurricanes are natural forces that cannot be replicated.

Further research could explore the damage to forests from hurricanes through an analysis that included more factors that can exert and influence in the degree of damage on forests, as well as different analysis for different categories of hurricanes and different climatic situations. Other ecosystem services can be included and analyses at different scales should also be done, because factors can vary across different scales. The identification of high forest damage risk zones is important for pre and post-hurricane forest management. Some forest management at the stand level can be done to minimize the risk of carbon and timber loss due to hurricanes, the management practices can be done before or after the hurricane impact. Overall, based on the literature review, decision tree analysis is not commonly used in this kind of study; however, it is a good alternative for assessing hurricane damage to forests. This method could also be applied at a state-level to identify high forest damage risk zones across the State of Florida. The potential for timber salvaging activities can be also included in the decision-tree analysis to identify areas after a hurricane. This study's decision tree could also be used to develop an online portal for landowners to know how vulnerable their forests are to hurricane impacts. The inclusion of urban areas in the analysis can also be done in future studies to have a complete idea about ecosystem services losses across all ecosystems in the watersheds.

Knowledge on the potential effects of hurricanes on forest ecosystems and their services is growing because of the predicted increase in hurricane intensity and occurrence. The study's results can serve to map and identify the most vulnerable zones, as well to evaluate how hurricanes can affect aboveground carbon storage, and consequently carbon sequestration in a long-term, and timber volume to intensify the management of the areas with high probability of ecosystem services loss. Land managers should include the potential occurrence of disturbances, such as hurricanes in their management plans to be aware of the consequences in terms of loss of ecosystem services especially when they have in mind some conservation strategies such as payment for ecosystem services.

Table 3-1. Description of the Forest Inventory and Analysis (FIA) attributes used in the hurricane framework. [Adapted from Woudenberg, S. W., Conkling, B. L., O'Connell, B. M., LaPoint, E. B., Turner, J. A., and K. L. Waddell. 2010. The Forest Inventory and Analysis Database: Database Description and User's Manual Version 4.0 for Phase 2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.]

Attribute code	Attribute	FIA Table name	Attribute description
UNITCD	FIA Survey unit	Condition, Tree, Plot	Survey units are groups of counties within each State
ECOSUBCD	Ecological Subsection	Plot	An area of similar surficial geology, lithology, geomorphic process, soil groups, sub-regional climate, and potential natural communities
COUNTYCD	County	Condition, Tree, Plot	The identification number for a county, a governmental unit in a State
COND_STATUS_CD	Condition status	Condition	The condition status indicates the basic land cover (e.g. forest land)
STDAGE	Stand age	Condition	The average age of the stand (years)
FORTYPCD	Forest description	Condition	Forest type code
DIA	Current diameter	Tree	Current diameter of the tree in inches.
HT	Total height	Tree	The total length of the tree (in feet) from the ground to the tip of the apical meristem.
BALIVE	Basal area	Condition	Basal area of live trees over 1 inch of diameter at breast height (in square feet per acre)

Table 3-2. Range of values for the two defined classes for tree diameter, tree height and basal area for the Lower Suwannee River and Pensacola Bay watersheds

Attribute		Value in Lower Suwannee River	Value in Pensacola Bay
Tree diameter	DIA 1	>=8.4 inch	>=7.5 inch
Tree diameter	DIA 2	<8.4 inch	<7.5 inch
Tree height	HT 1	>=45.8 feet	>=50 feet
Tree height	HT 2	<45.8 feet	<50 feet
Basal area	BA 1	>=80 square feet/acre	>=68 square feet/acre
Basal area	BA 2	<80 square feet/acre	<68 square feet/acre

Table 3-3. Expressions used in the Conditional function in ArcGIS® Spatial Analyst to define the risk of forest damage by hurricanes

Area of damage	Expression	Risk of forest damage
High forest risk damage zone: 1	Land cover = softwoods and Area of damage = 1 and mean height = 1 and mean diameter= 2 and basal area = 2	High
Moderate or Low forest risk damage zone: 2	Land cover = hardwoods and Area of damage = 2 and mean height = 1 and mean diameter = 1 and basal area = 2	High

Table 3-4. Potential aboveground carbon, timber net volume, and timber in the sawlog portion in the forest damage risk zones for the Lower Suwannee watershed

Risk zone	Area (ha)	Aboveground carbon (Mg)	%	Timber net volume (m^3)	%	Timber sawlog portion (m^3)	%
Low	162,435	7,076,490	69	17,337,987	85	10,563,310	68
High	23,841	3,117,150	31	3,064,328	15	4,913,881	32
Total	186,276	10,193,640	100	20,402,314	100	15,477,192	100

Table 3-5. Potential aboveground carbon, timber net volume, timber in the sawlog portion in the forest damage risk zones for the Pensacola Bay watershed

Risk zone	Area (ha)	Aboveground carbon (Mg)	%	Timber net volume (m^3)	%	Timber sawlog portion (m^3)	%
Low	53,904	1,384,500	99.5	3,681,811	99.3	2,950,522	99.5
High	170	7,547	0.5	27,391	0.7	13,661	0.5
Total	54,074	1,392,047	100	3,709,202	100	2,964,183	100

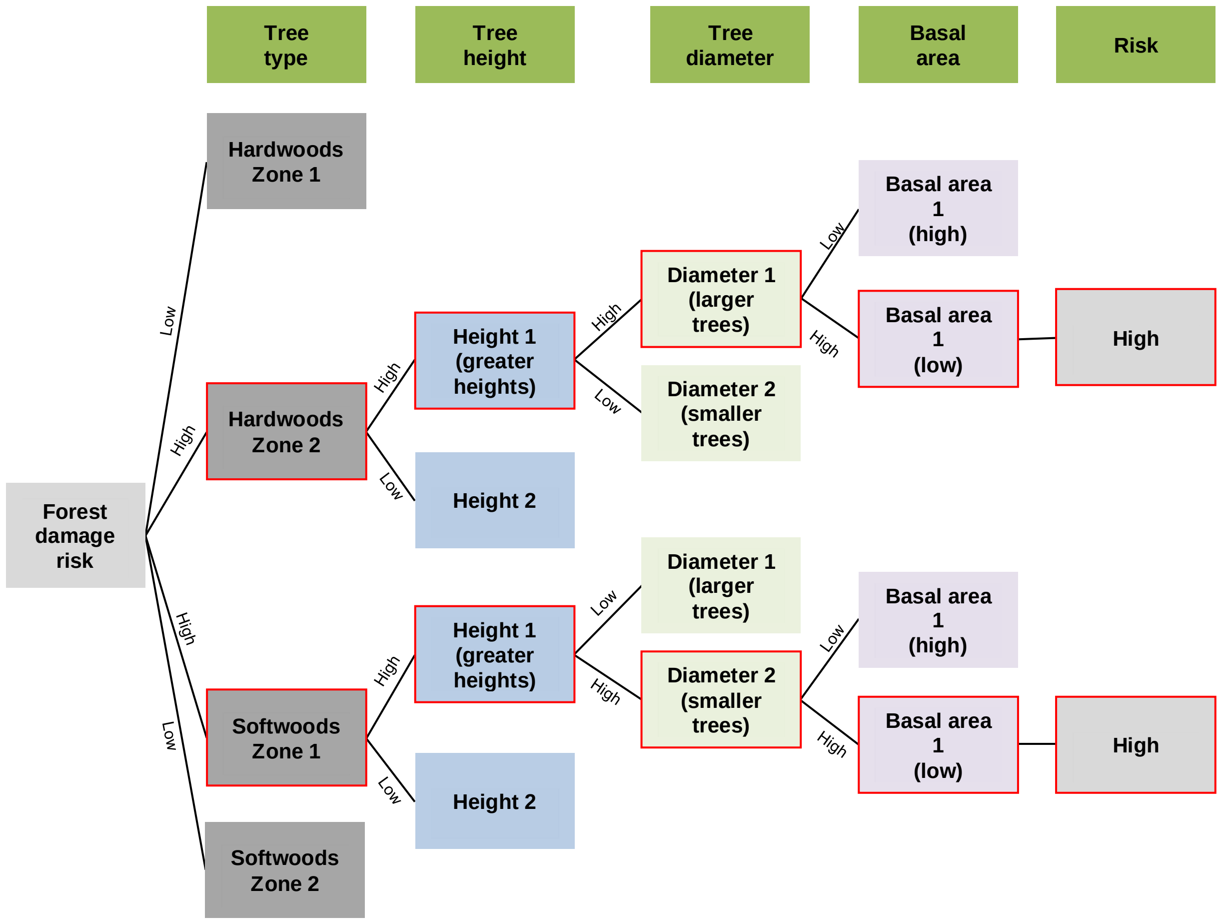


Figure 3-1. Decision tree scenario for determining forest damage risk due to hurricanes

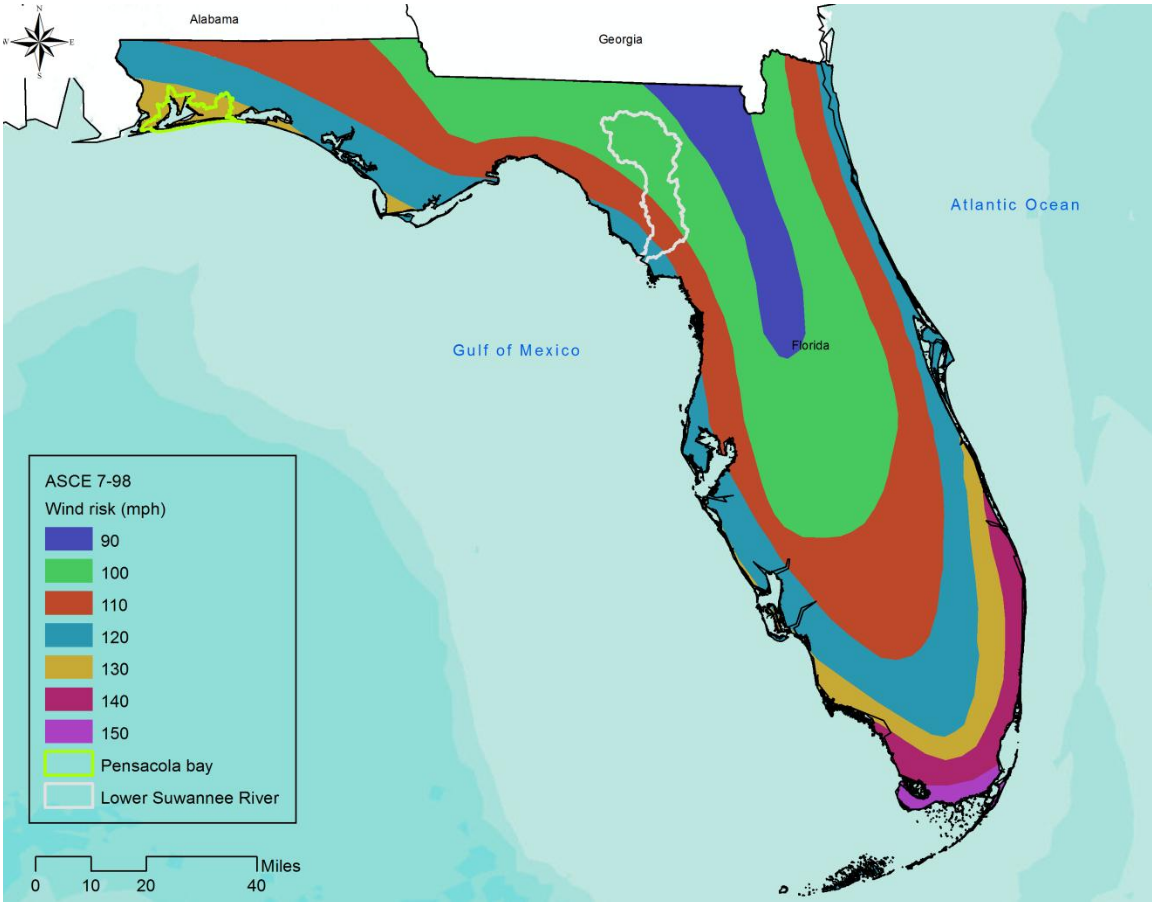


Figure 3-2. American Society Civil Engineer's Standard (ASCE) 7-98 map with wind risks for the two watersheds: Lower Suwannee River and Pensacola Bay. [Adapted from Peacock, W. G., Brody, S. D., and W. Highfield. 2005. Hurricane Risk Perceptions among Florida's Single Family Homeowners. (Page 127, Figure 1). Landscape and Urban Planning.]

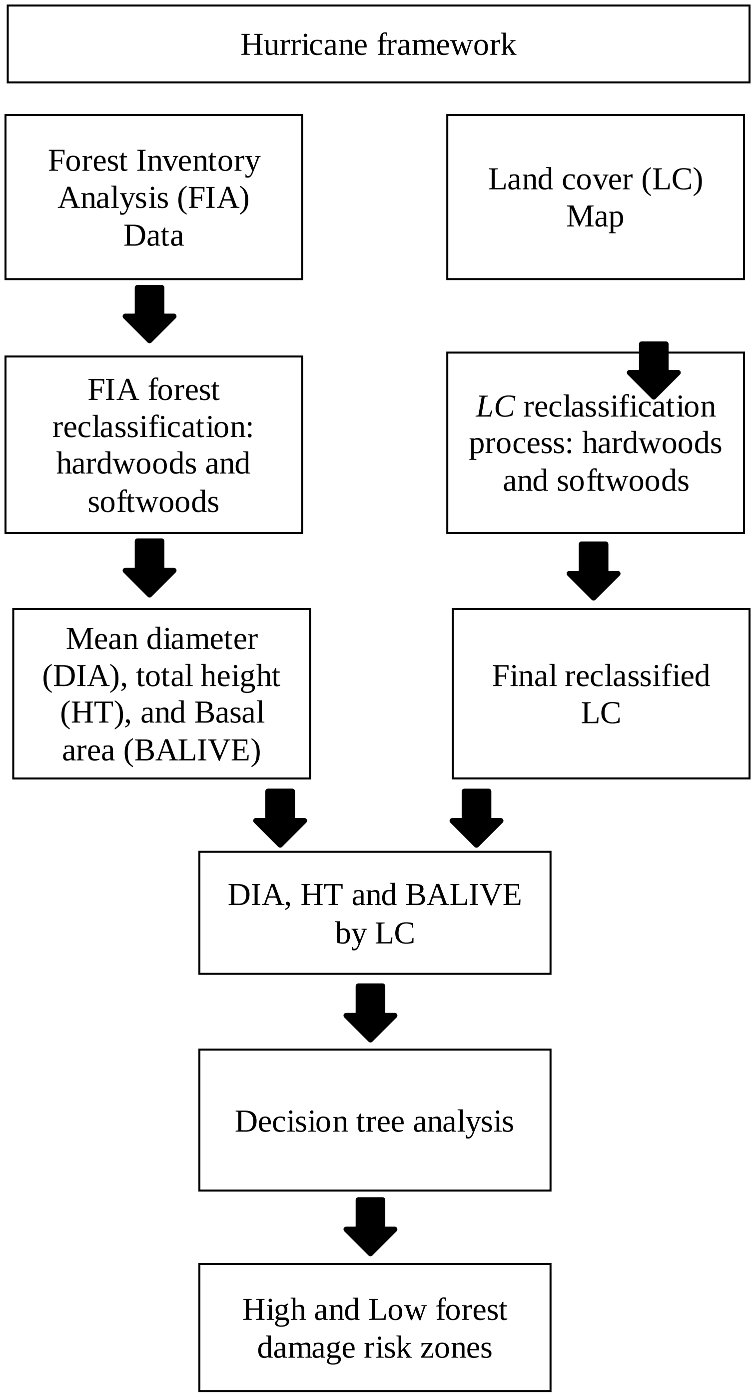


Figure 3-3. Flow chart for the decision tree analysis for determining forest damage risk zones

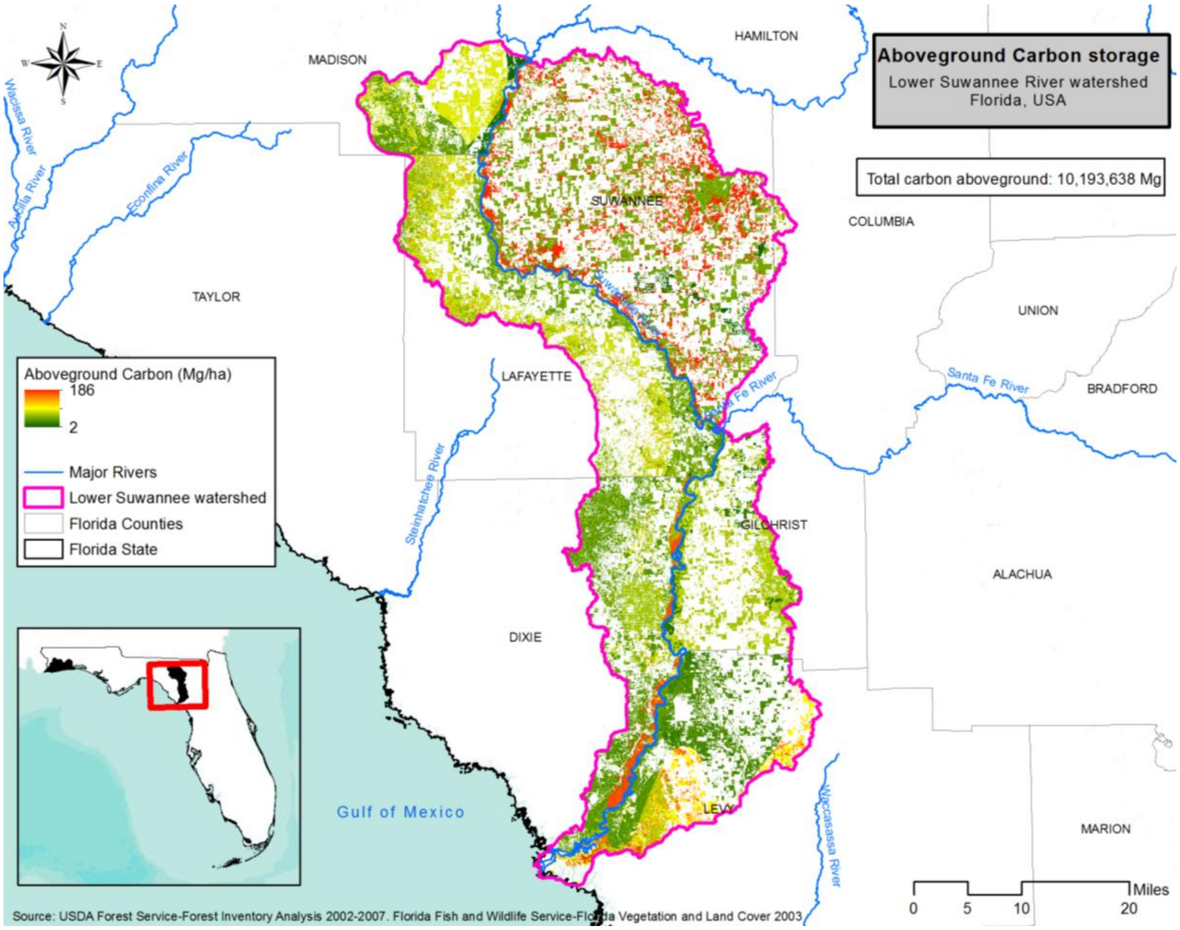


Figure 3-4. Aboveground carbon storage in the Lower Suwannee River watershed in 2003

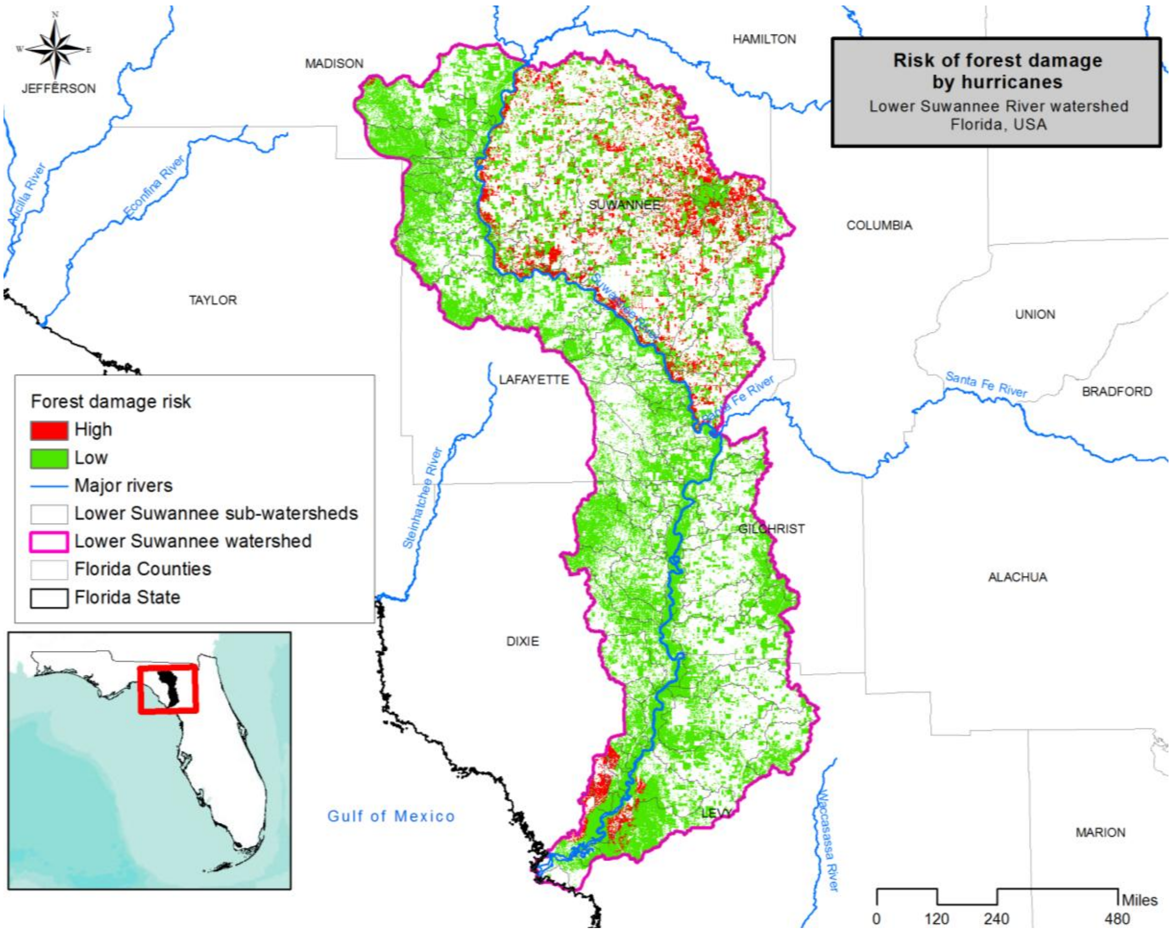


Figure 3-5. Risk of forest damage by hurricanes in the Lower Suwannee River watershed

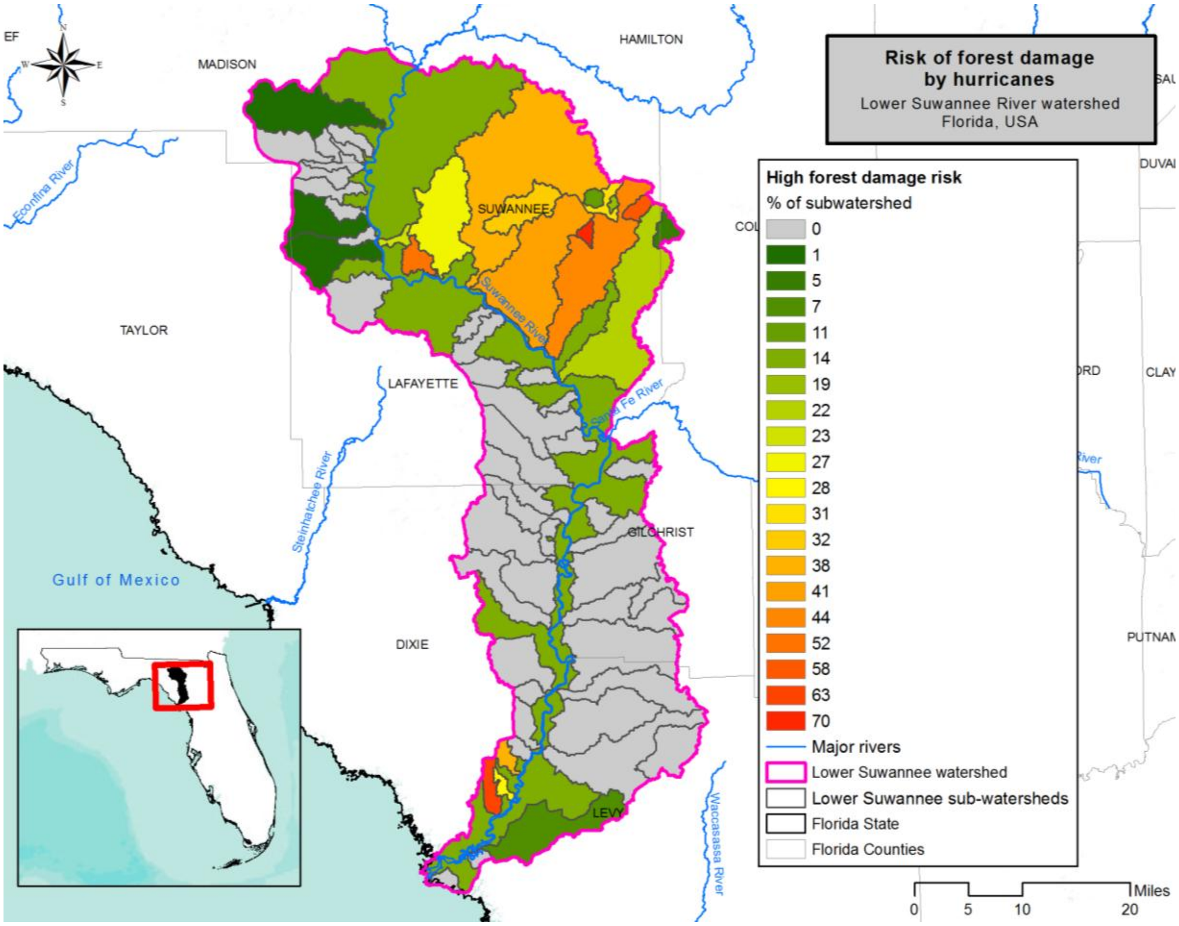


Figure 3-6. High risk of forest damage by hurricanes in the Lower Suwannee River watershed by sub-watersheds

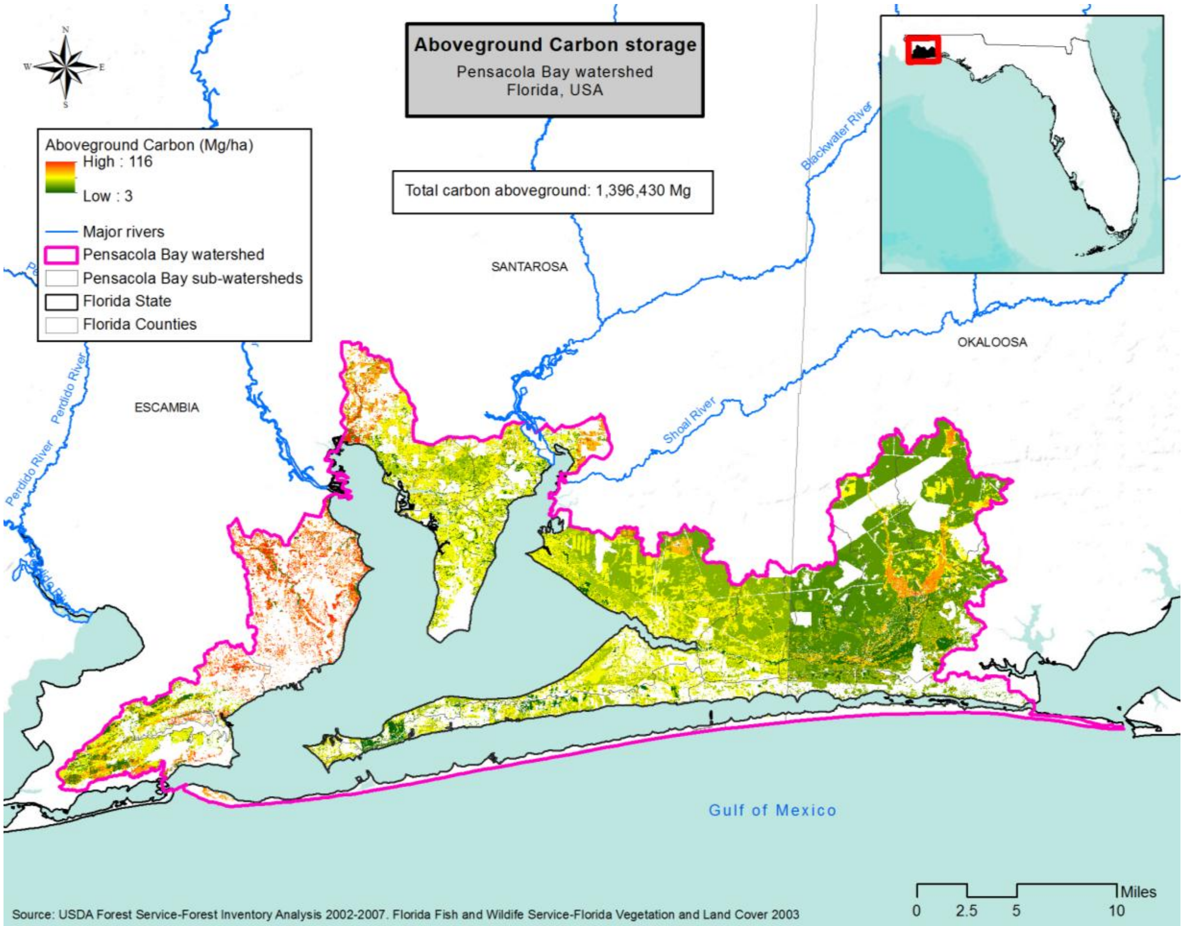


Figure 3-7. Aboveground carbon storage in the Pensacola Bay watershed in 2003

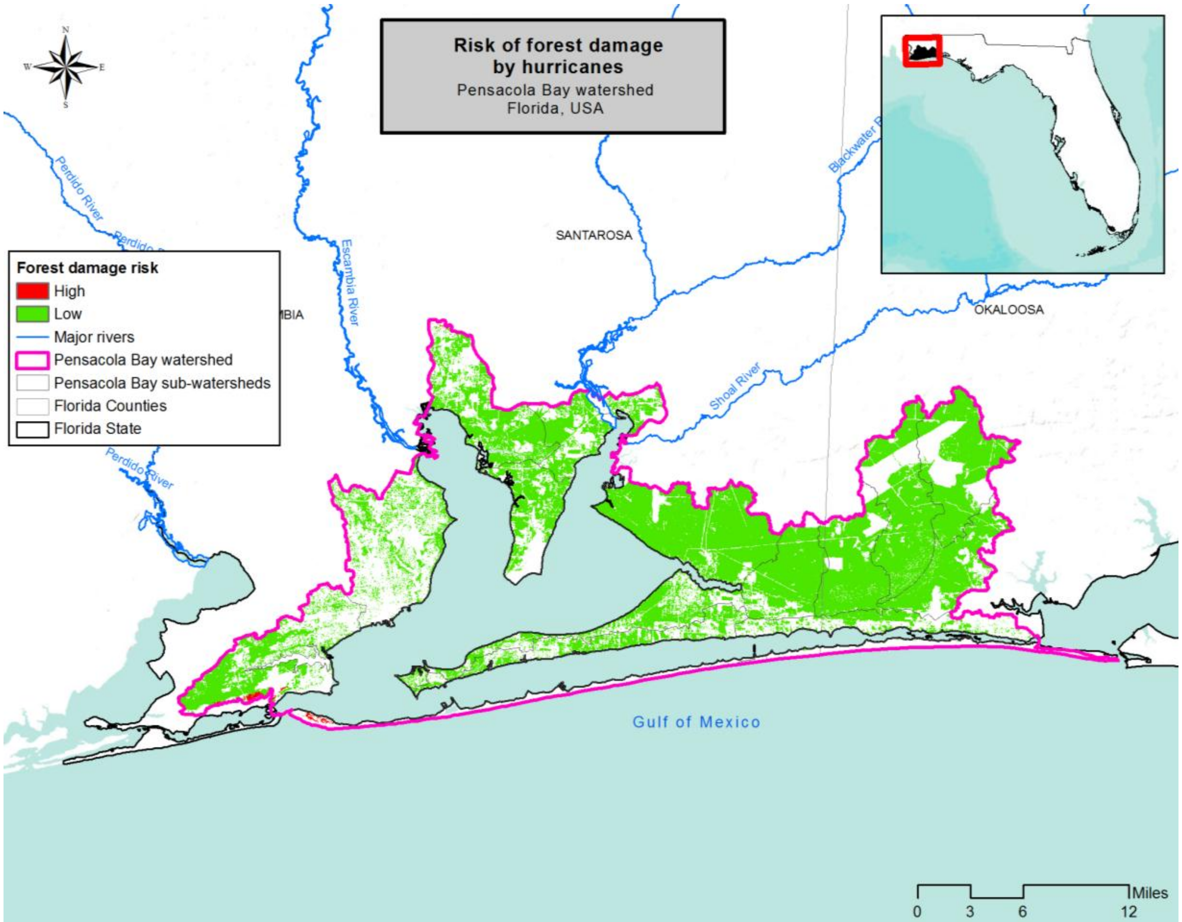


Figure 3-8. Risk of forest damage by hurricanes in the Pensacola Bay watershed

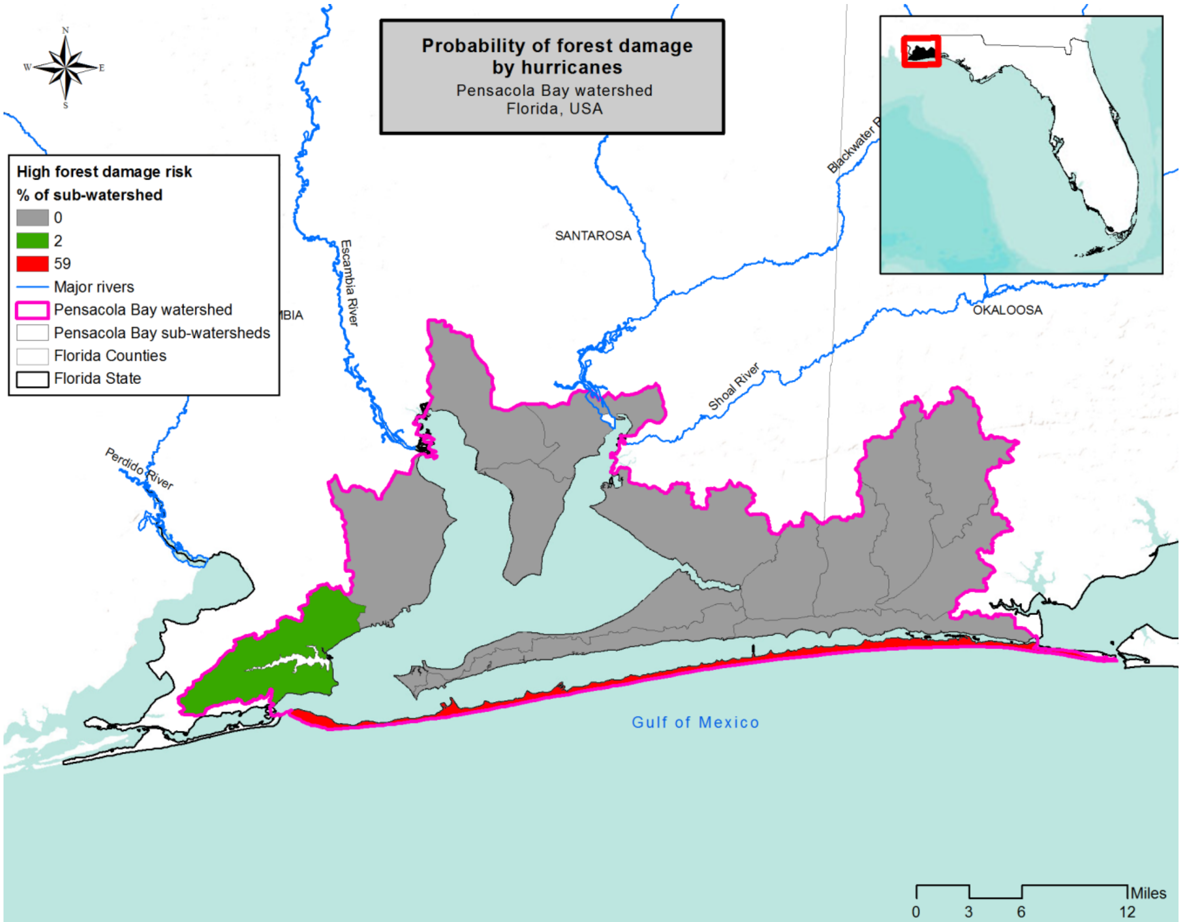


Figure 3-9. High risk of forest damage by hurricanes in the Pensacola Bay watershed by sub-watersheds

CHAPTER 4
CONCLUSIONS

Summary

The concept of ecosystem services is becoming more relevant to environmental planning and management (Boyd and Banzhaf, 2007; Brown et al., 2007; de Groot et al., 2010; Farley and Costanza, 2010). The Millennium Ecosystem Assessment (2003) defined ecosystem services as those services provided by ecosystems with a direct influence on human well-being. The southern US forests are one of the most biologically diverse temperate forests in the world and consequently they can produce a bundle of ecosystem services (i.e. a set of multiple ecosystem services) (Raudsepp-Hearne et al., 2010). Although, people can benefit from multiple ecosystem services; they often have to decide which services are more relevant to them depending on what benefit they want from these ecosystems. So, the inclusion of the population in the decision-making process is key to know what ecosystem services are important for a region.

Change in land cover can affect the provision of ecosystem services by reducing them. All ecosystems constantly change over time, and many of these changes are due to human impacts (e.g. urbanization) and natural processes (e.g. wildfire) (ICSU et al., 2008; Millennium Ecosystem Assessment, 2003). Understanding the causes of these changes, or drivers as done in this study, is fundamental to minimize their impact on the provisioning of ecosystem services, as well as on the human well-being (Millennium Ecosystem Assessment, 2003).

Effects of Urbanization on Carbon Storage, Timber Volume, and Water Yield

Ecosystem can be impacted from different drivers that can alter their functionality, as well as their processes and services. The first step in understanding the magnitude of the impacts to ES provision is to quantify ES as well as the drivers affecting them. Urbanization, defined as the development of new urban areas in non-urban lands, is considered one of the major drivers that can affect ecosystems (Grimm et al., 2008; Xu et al., 2007). As urbanization areas increase, ecosystems functions, processes and services can be impacted. This study estimated the effects of urbanization as a driver of carbon storage, timber volume, and water yield in the Lower Suwannee River and Pensacola Bay watersheds in Florida. The study combined Geographic Information System (GIS) and Forest Inventory and Analysis (FIA) data to estimate ES using a 2003- current scenario and a projected 2060 urbanized-scenario in these two areas. The Integrated Valuation and Ecosystem Services Tradeoffs (InVEST) GIS model was used to quantify the ecosystem services.

Results show that there were significant changes in the two study areas between the current and urbanized 2060 scenarios in terms of provision of the three ecosystem services. Thus, urbanization directly affects carbon storage, timber volume, and water yield; carbon storage and timber volume were negatively correlated to urbanization and water yield was positively correlated. Results showed that urbanization will convert forest areas in the year 2060, and that will be result in the decrease of the provision of carbon storage and timber volume, and into an increase in water yield.

Potential Loss of Aboveground Carbon Storage and Timber Volume from Hurricanes

Hurricanes are also a driver affecting ecosystems, as well as its processes and services. This study identified forest damage risk zones due to hurricanes that can be useful for landowners and policy makers and is crucial for management purposes. This study also estimated the potential loss of ecosystem services in terms of aboveground carbon storage and timber volume by hurricanes, in the Lower Suwannee (LS) and Pensacola Bay (PB) watersheds in Florida. The identification of the high and low probabilities zones were based on five factors identified in previous studies as important for determining the degree of forest damage: tree diameter and height, distance to landfall, type of species (e.g. hardwoods or softwoods), and basal area. A decision tree framework was developed based on five factors identified in previous studies as important for determining the potential damage in forest due to hurricanes. Those factors were: tree diameter and height, distance to landfall, type of species (e.g. hardwoods or softwoods), and basal area. Results showed that this method can be used to determine potential losses of aboveground carbon storage and timber volume due to hurricanes in the Lower Suwannee River and Pensacola Bay watersheds.

Integrating the Concept of Ecosystem Services in Decisions

One of the major challenge that scientist are facing is the translation of ecosystem services into action. The objective of this is to make better decisions, resulting in better use of the natural resources (Daily et al., 2009). Several studies have been done for evaluating ecosystem services in different aspects (Liu and Costanza, 2010; Millennium Ecosystem Assessment, 2003; Nelson et al., 2009); however not many of them have been put in practice. So, the integration of ecosystem services in decisions becomes very important to improve human life. Decisions in terms of land use change have been done base only in economic aspects putting aside ecological aspects (McKenzie et al., 2011).

As a result of the lack of information on the quantity and value of ecosystem services, some land covers that are multifunctional (and consequently multiple ES provision) are converted often to single-functional land covers (e.g. croplands).

Therefore, to produce the information about ecosystem services and how these are affected by different drivers is the first step to include them in the decision-making process. The next step is to put that information available to the public, land owners, policy makers, urban planners, and others decision makers but in a very clear, simple and understandable way. Other effective strategies are education and awareness programs for all who lack information (McKenzie et al., 2011). Daily et al. (2009) for example, presented a framework to integrate ecosystem service into decisions, they started describing the how decisions are linked with ecosystems, they proposed the use of scenarios to see the effects of decisions on ecosystems. Next, they mention the importance of knowing about ecosystem services and their values to provide this information to the institutions that have the power to create, for example conservation incentives.

Integrating ecosystem services into policies is not impossible. There are some examples, ecosystem services are included in the National Strategy for Growth and Reduction of Poverty of Tanzania for the year 2005 (McKenzie et al., 2011). Basically they include the protection and enhancing of ecosystem services to improve the welfare of people. Information about ecosystem services can also influence decisions, this is the case of Borneo, there was an interest in change a forest area to an oil palm plantation; however, an assessment on the values of ecosystem services favor the forest area over the oil palm plantation (McKenzie et al., 2011). The Millennium Ecosystem Assessment (2005) presents several other examples.

Even though several studies have been done to show the consequences of ecosystem service changes on the population, if people’s perception about ecosystems does not change, no possible study can have any impact on them (McKenzie et al., 2011). Therefore, if people do not value nature and they are more interested in short-term economic growth; the integration of ecosystem services in decisions will be very difficult (Daily et al., 2009; Nelson et al., 2009). In conclusion, when people begin understanding the importance of ecosystem services to their well-being incorporating ecosystem services into policies will become easier.

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BIOGRAPHICAL SKETCH

Sonia Elsa Rocio Delphin Perez was born in Asuncion, Paraguay in 1980. She got a bachelor degree in forest engineering from the National University of Asuncion in 2005. Her thesis analyzed forests fires based on remote sensing and geographic information systems (GIS) methods. After graduation, she joined an environmental consulting firm focusing her work in the use of GIS to analyze forest ecosystems. She worked there for 2 and half years. Later, she started working for World Wildlife Fund (WWF) in Paraguay as a GIS analyst. Her work was focused on the monitoring of the deforestation in the Upper Parana Atlantic Forest in the Eastern Region of Paraguay based on Landsat satellite imagery. Her job also included different GIS analysis of forests and GIS training to environmental employees from the Paraguayan Government. She has been working there for 2 and half years. During that time she continued her education in GIS and remote sensing at the Kansas State University and the Polytechnic University of Madrid. She entered at the School of Forest Resources and Conservation at the University of Florida in the fall 2010 to get a master’s degree and she was graduated in August 2012.