Climate change and land use in Florida: Interdependencies and opportunities

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Executive summary

Over this century anthropogenic climate change will present significant challenges to Florida and to the world, as it will influence nearly every aspect of our planet's living systems and human economy. Nations that preserve their cultural heritage, environmental integrity, and economic stability will be those that are leaders in implementing plans to mitigate and adapt to the effects of climate change. Florida has recently committed to join a coalition of states belonging to a climate registry and has begun statewide measures toward developing tools for mitigating the effects of climate change. The first step in developing a climate action plan for the state is to construct a comprehensive greenhouse gas (GHG) inventory, which the Florida Department of Environmental Protection will develop over the next year. In addition to a GHG inventory and mitigation tools, a state climate action plan must consider the inevitable effects of climate change. Specific land use practices in Florida can be utilized to increase the state's capacity to respond skillfully to anticipated changes in climate, and position Florida to be a major player in carbon markets, supporting economic development of the state.

- The task of predicting how Florida's climate will change over the next 100 years is challenging given the current state of climatology. Only general trends are known for the southeastern US; a review of Florida's past climate data on a fine spatial scale would provide a baseline for projecting future climate change.

- General circulation models are not able to explicitly project regional and local climate variability for Florida. Projections for the Southeast region as a whole indicate average temperature increases from a few to more than 10 degrees F, and varying increases or decreases in precipitation and drought depending on location by 2100.

- Florida's climate is strongly affected by the Gulf of Mexico and the Atlantic Ocean. Models that incorporate the effects of the Atlantic Multidecadal Oscillation, the El Niño Southern Oscillation, and the North Atlantic Oscillation are necessary for more reliable projections.

- The science for sea-level rise continues to unfold. A reasonable projection is that seas will rise in a nonlinear fashion by 3 ft, and possibly much more, by 2100. Proactive adaptation of coastal lands can lessen the consequences of sea-level rise for human populations and coastal ecosystems.

- Florida's population will likely increase by 50 percent over the next 25 years. Studies predict that 7 million additional acres will be developed by 2060, and that 2-3 million acres of aquifer recharge lands will be developed by 2020.

- Land use changes strongly influence regional climate, and over relatively short timescales this effect can be greater than the atmospheric forcing from greenhouse gases. Changes in vegetation cover significantly affect local variation in temperature and precipitation. Regional climate models are needed to better understand the effects of land use change on mesoscale climate.

- The urban heat island effect has increased for many of Florida's urban areas as sprawl propagates the extent of impervious surfaces. This trend is likely to increasingly dominate urban climate.

- Florida ranks sixth in the US for total GHG emissions. The agricultural sector in Florida is a net emitter of GHGs, while the forestry sector is a net sink.

- The forestry and agriculture sectors of Florida represent the greatest potential for offsetting and mitigating projected increases in fossil emissions over future decades.

- On average, Florida soils have the highest organic carbon content of the coterminous United States. The agriculture sector can mitigate greenhouse gases through increased carbon sequestration in soils by low-till and no-till farming, and removing marginal land from production. A tailored mix of tillage, fertilizer application, and crop rotation can enhance carbon sequestration.

- Florida crop and pasture lands represent an opportunity for agricultural production of biofuels, which can displace the use of fossil fuels. Sugar cane in Florida holds the greatest potential for ethanol production from carbohydrate, but current market subsidies preclude its development. The most favorable yield with respect to GHGs comes from the use of plant cellulose to produce ethanol. Efforts are currently underway to commercialize the production of cellulosic ethanol in Florida.

- Florida has significant potential to generate power from biogas derived from waste at agricultural operations, especially feedlots. Biogas can be produced in fixed-film digesters recently developed at the University of Florida.

- Covering over 42 percent of the state, forests are the largest landscape source of climate mitigation capacity in Florida through carbon stored in standing biomass, below ground, and in forest products. Wood can be used for fuel and other products currently derived from fossil fuels. Direct combustion of woody biomass holds great promise for displacing coal in power plants in Florida.

- Afforestation and tree planting on agricultural lands can provide significant ecosystem carbon sequestration. Because of Florida's warm climate, afforestation is a viable mitigation option and could provide an advantage for participation in carbon markets.

- It is unclear how anthropogenic climate change will affect Florida's wetlands, but maintaining hydroperiod and controlling wildfires during dry periods can reduce losses of carbon stocks.

- Florida can participate in a mandated cap-and-trade system to limit total emissions allowable in regulated activities through carbon credits traded on an open market.

Mandatory federal caps are necessary for such markets to be significant in greenhouse gas management. Trading allowances must include reversal and leakage in their accounting of offsets.

- GHG offsets derived from land-management activities must be additional and are estimated by calculating the net GHG benefits and estimating leakage from a project. An independent party must verify a site-specific monitoring and quantification plan before any offsets can be marketed. Offsets can be aggregated and sold by retailers and brokers, who are often in a better position than landowners to make up for shortfalls.

- The development of land use planning in the face of climate change should include a comprehensive inventory of Florida's lands and waters. These data can inform the extent to which land use scenarios for climate mitigation can also conserve ecosystem services. CLIP (Critical Lands/Water Identification Project) is a useful tool for this purpose.

- Failure to develop and implement appropriate plans for climate mitigation and proactive adaptation could cost the state billions in lost revenue. Overall, adaptation to climate change will not be a smooth or cost-free endeavor. Significant opportunity exists for economic development through land management for climate mitigation and participation in carbon markets.

Land use and climate change in Florida are deterministically linked issues. Current projections of development within Florida are not consistent with either the goals of sustainable development or maximizing the opportunity for climate mitigation and adaptation through land management. Florida is uniquely endowed to become a leader in greenhouse gas mitigation through the effective management of agriculture, forestry, and natural ecosystems, but realizing this potential requires that policy makers consider competing land uses and their potential consequences. Appropriate land management and sustainable development can be partly driven by the economic incentive provided by carbon markets. Land use approaches to mitigation must consider the implications for sustainability through comprehensive planning over a timescale of at least a century. To the extent that enhanced carbon sequestration is consistent with maintenance of ecosystem services, creation of carbon offsets through land use represents the first step toward reconciling the planet's living carbon economy with its monetary economy. Properly implemented, sustainable land-management strategies for climate mitigation can be socially, environmentally, and economically viable, and can create jobs and opportunities for enhancing the wellbeing of Floridians for generations to come.

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Introduction

Anthropogenic climate change is now widely regarded as possibly the most significant challenge facing humanity. Climate change over the next 100 years and beyond will affect virtually every aspect of living systems in Florida and the world. In June 2005, eleven of the worlds leading national academies of science issued a joint statement noting that it is imperative that we aggressively mitigate the causes of climate change and prepare to adapt to a changing climate. On February 2, 2007, the United Nations Intergovernmental Panel on Climate Change (IPCC) issued its fourth assessment report (AR4) of the physical science of the earth's climate stating that "most of the observed increase in globally averaged temperatures since the mid 20th Century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." The panel stated further that the "warming of the climate system is unequivocal" and that there is "very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming." This report from Working Group I was followed in subsequent months by assessments of impacts (Working Group II) and recommendations for measures that could stabilize the climate system through mitigation of the greenhouse gases (Working Group III). Over the last 100 years, the earth's atmosphere has warmed about 1.4°F (Hansen et al. 2005). There is broad scientific consensus that the greenhouse gases (GHGs) must be reduced 60 to 80 percent relative to 2000 levels by 2050 (Socolow and Pacala 2004) to avoid dangerous anthropogenic climate change (Hansen et al. 2007), including sea-level rise of 3 ft or more (Rahmstorf 2007). Failure to mitigate anthropogenic climate change could cost the human economy up to 20 percent of annual world gross domestic product by 2100, arguably resulting in one of the greatest market failures in history (Stern et al. 2006).

One effect of these assessments has been to move policy makers toward efforts to reduce the production of GHGs and increase the potential for natural and managed systems to mitigate climate change. Although Europe and the UK have made significant progress toward developing tools for mitigation, the US has only recently begun to develop such programs, largely through action at the state level. Responding to this call, Governor Charlie Crist in his first state-of-the-state address proclaimed that Florida should become a "leader" in addressing climate change, explicitly targeting Florida's GHG emissions as a focus of the state's efforts. Since 2000, 20 states have created or begun development of state climate action plans. As recently mandated by the legislature, the Florida Department of Environmental Protection is conducting a greenhouse gas (GHG) inventory for the state. The Governor recently committed Florida to join a coalition of states belonging to a climate registry, and in July 2007, hosted a climate summit in Miami to bring together stakeholders, scientists and prominent politicians. The Florida Energy Commission and other state agencies are developing additional plans.

Progress toward development of sustainable use of Florida's social, natural, and economic resources will be largely determined by how we respond to climate change. In the following I will outline components of a state climate action plan as they relate to land use. Such a plan should include more than the obvious elements of a GHG inventory and tools for mitigation. Because of significant warming latent in the earth's climate, we must also plan for inevitable climate change. Thus elements of adaptation should be part of any such plan. Here I will discuss specific areas related to land use where Florida can enhance resilience in the face of anticipated changes in climate, while developing the capacity to participate in carbon markets and support economic development of the state.

Climate projections for Florida

Florida has three distinct climate zones (Figure 1), and we can assume that global warming will shift these northward. Thus, much of the peninsula will become progressively tropical in character, but the speed and character of this shift are uncertain. The wintertime southernmost extent of frost will move north of its present location, which approximates the Florida-Georgia border. In order to develop appropriate strategies for land use to enhance mitigation and adaptation, we need to more explicitly predict how Florida's climate will change over the next 100 years and beyond. This is challenging given the current state of climatology. Surprisingly, there are no comprehensive analyses showing how Florida's climate has changed over the 20th century, although general trends are known for the Southeastern US (discussed below). A review of Florida's past climate data on a fine spatial scale would provide an important baseline from which to project future climate change.

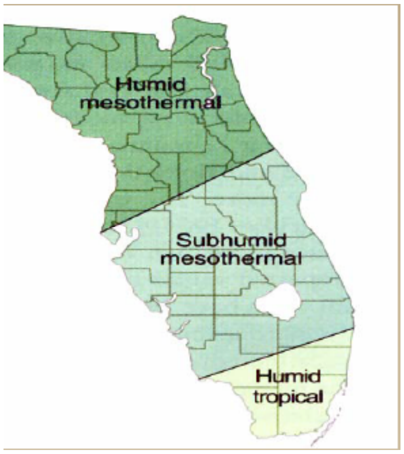


Figure 1. Climate zones of Florida.

Limitations of general circulation models. The general circulation models (GCMs) from which globally-averaged temperatures are projected are not able to resolve fine scale regional and local climate variability. This is a significant shortcoming because people experience climate locally rather than globally. While more stable and useful for global projections than meteorological models, which are sensitive to small errors in starting conditions, GCMs cannot predict weather for a given location (McGuffe and Henderson-Sellers 2005). As reviewed below, the current GCMs provide only coarse-scale projections of Florida's climate. Models developed during the 1980s resolved the atmosphere above land areas for grid cells of about 6 degrees latitude by longitude. Current models have more than 300,000 atmospheric grid cells, a couple million ocean grid cells, and thousands more for the land and sea ice components (McGuffie and Henderson-Sellers 2005). Models currently under development resolve the atmosphere above land to 2 degrees and include climate feedbacks from the biosphere. GCMs run on the world's fastest computers, and advances in modeling are dependent on advances in computational power.

With its extensive coastline, Florida's weather is strongly influenced by the Gulf of Mexico to the west and the Atlantic to the east. Precipitation and temperatures throughout the state vary partially as a function of the Atlantic Multidecadal Oscillation (AMO), an ongoing series of long-duration changes in sea surface temperature (Enfield et al. 2001). When the Atlantic is in its warm phase, rainfall is greater in central and south Florida, but lower in north Florida, while the opposite pattern prevails during the cool phase. A general statement can be made that Florida should warm at a rate that reflects its linkage to the ocean heat content as driven by global warming, but the AMO can both exaggerate and mask this effect (IPCC 2007; Knight et al. 2005). The next generation of GCMs will permit greater resolution of this ocean effect, and more explicit projections for the interior of the peninsula.

Projections for the Southeast. In lieu of explicit projections for Florida, we can get an indication of how the state's climate may change by looking at projections for the Southeast, a region large enough to result in robust products from the GCMs. The most recent comprehensive assessment of regional climate change in the southeastern US was published by the US Global Change Research Program (USGCRP) in 2000. An assessment scheduled for 2005 has not been produced, and is now scheduled for release in late 2007. Similar to much of the continental US, the record shows that the Southeast experienced a warm period during the 1920s-1940s, a cooling trend during the 1960s, and since 1970 temperatures have been increasing. Annual rainfall has increased 20-30 percent over the last 100 years through much of this region, while most of Florida showed no strong trend. Figure 2 shows projected changes in temperature and precipitation based on the Canadian and Hadley GCMs developed during the 1990s. The Hadley model shows warmer temperatures and somewhat more precipitation for Florida during the 21st century. The Canadian model shows significantly higher temperatures and lower precipitation than the Hadley model. A recent analysis of satellite observations indicates that atmospheric water and precipitation and have increased to the same degree in response to global warming over the last two decades, and this suggests that current models may underestimate the projected increase in precipitation (Wentz et al. 2007).

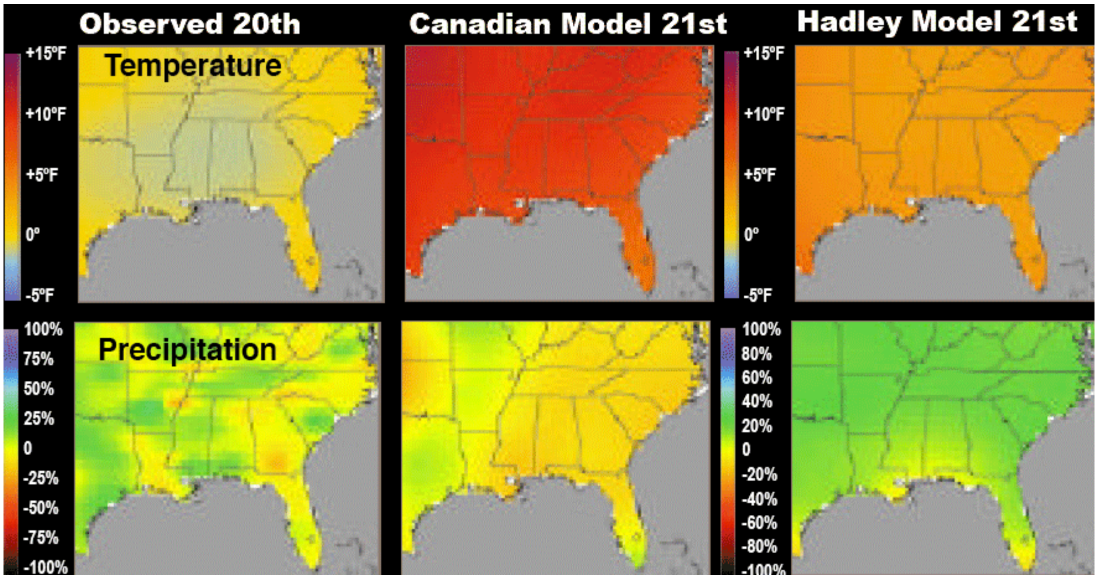


Figure 2. Observed and modeled temperature (top) and precipitation (bottom) for the Southeast (USGCRP 2000).

The USGCRP models show mixed results with respect to Florida's summer soil moisture content (Figure 3). The Canadian model projects that drought will be more frequent in Florida, while the Hadley model suggests that the northern part of the state will have more soil moisture.

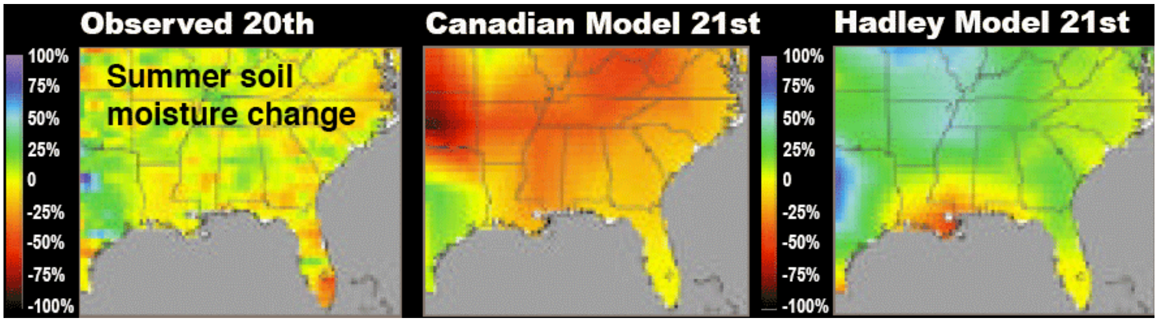


Figure 3. Observed and modeled summer soil moisture for the Southeast (USGCRP 2000).

Crop yields and forest productivity in Florida are not simple functions of precipitation and temperature. The Hadley model indicates that rainfed crops in Florida will exhibit both increased and decreased yield by 2030, depending on crop and location (Figure 4). The USGCRP (2000) used a forest process model to evaluate the impact of the Hadley climate scenario and increasing atmospheric CO_2 on southeastern forest productivity. The model projects that by 2100 the southern hardwoods will be much more productive than pines. This could result in slightly higher softwood prices and lower hardwood prices. The Canadian model suggests that forest productivity would be negatively affected for both pines and oaks, with an increase in savanna or scrub habitat in Florida.

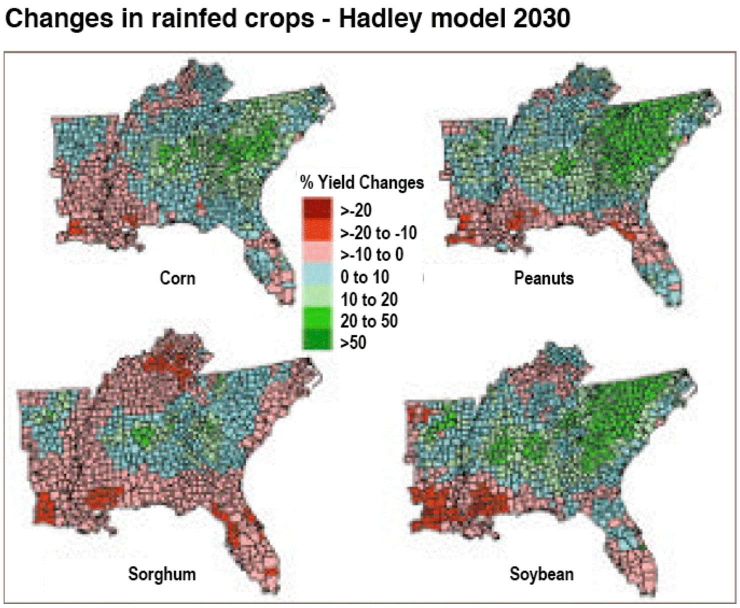


Figure 4. Projected changes in 30-year averaged rainfed crops of four major crops in the Southeast by 2030 (USGCRP 2000).

The USGCRP model results shown above should be viewed as reasonable projections derived from GCM models available during the1990s, and they provide a general indication of what to expect. They are not adequate for planning purposes for the three climate zones of Florida because of their relatively crude resolution and the strong influence of the oceans on Florida climate. Work is ongoing at institutions such as the US National Center for Atmospheric Research and the UK Hadley Center to develop regional climate models with more predictive power.

Sea-level rise. One important effect of climate change that has dominated the concerns of policy makers in Florida is sea-level rise and its potential effects on coastal land use and ecosystems. The science for sea-level rise continues to unfold in the peer-reviewed literature. Based on publications through mid 2006, the IPCC AR4 (2007) projected that sea level will rise globally between 7 and 23 inches by 2100, excluding the effects of ice flow on the Antarctic peninsula and Greenland, and carbon cycle feedbacks on the atmosphere such as the progressive thawing of permafrost in the far north. More recent analysis of sea-level data from shoreline measures and satellite altimetry show that the last 15 years have seen the fastest rate of rise since records have been kept. Moreover, seas are rising at the upper limit of the rate projected by the IPCC Third Assessment (Rahmstorf 2007). This rate of rise cannot be accounted for by thermal expansion of the ocean surface water, and likely also reflects the melting of ice on land, such as Greenland. Based on these data, a reasonable projection for global sea-level rise is 3 ft by 2100. Ice melt is inherently nonlinear, and Hansen et al. (2007) project a tipping point at mid-century which could result in rapid and extensive sea-level rise in excess of 3 ft unless CO_2 levels are kept below 450 ppm (parts per million per volume air; presently at 387 ppm). More precise estimates of sea-level rise for the coasts of Florida are not possible given our current state of knowledge.

Sea-level rise threatens low-lying coastal ecosystems globally. Chronic saltwater contamination of forest soils has occurred along Florida shorelines as sea levels have risen over the last century, resulting in osmotic drought stress and eventual death of trees. Since 1991, there have been massive die-offs of Sabal Palm (*Sabal palmetto*) and other trees along a 40-mile stretch of coast between Cedar Key and Homosassa Springs. Older trees that did manage to survive often failed to produce new seedlings (Williams et al. 1999). Coastal forest loss and loss of mangrove and salt marsh ecosystems will be increasingly severe as sea level rise accelerates under global warming. Loss of mangroves will leave coastal areas more vulnerable to storm surge from hurricanes.

Stronger hurricanes possible. The frequency and intensity of hurricanes making landfall on the Florida peninsula vary complexly as a function of many factors, including the AMO, the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO; Goldenberg et al. 2001). Because sea surface temperatures are a primary determinant of hurricane strength, some scientists have projected that hurricanes will become more intense due to warming of the ocean's surface waters (e.g., Emanuel 2005; Elsner 2006), while others have argued that strong hurricanes may become less frequent due to projected increases in wind shear under conditions of anthropogenic climate change (Vecchi and Soden 2007). The IPCC AR4 (2007) states that stronger hurricanes are "likely" (greater than 66 percent probability) during the first part of the 21st century, but recent data indicate that the number of strong Atlantic hurricanes since 1990 may not be unusual (Nyberg et al. 2007). Although the implications for Florida are profound, the science regarding the effect of climate change on hurricanes remains unresolved.

Land use projections for Florida

Perhaps the most important economic and political issue facing Florida over the next decade is land use. The forest, agricultural, and natural lands in Florida have yet to be managed for GHG offsets and mitigation, and thus they represent obvious targets for inclusion in a climate action plan for the state. Assuming that Florida chooses to participate in mitigation efforts, policy makers will need to make hard choices between urban expansion and alternative land uses associated with GHG mitigation and adaptation. Even assuming a net reduction in immigration to the state, Florida's population will likely increase by at least 50 percent over the next twenty-five years, and may double in fifty years. Urban development, suburban sprawl, transportation pressures, coastal human population densities, habitat fragmentation, and reduced agricultural and forest lands will be the inevitable result of this population increase unless growth is managed wisely with attention to enhancing sustainability (Mulkey 2006). The constraints on land use and natural resources are made ever more critical by the unfolding consequences of climate change, which will impact densely populated coastal regions as sea level rises. The central challenge and opportunity for Florida policy makers is to include the potential for GHG mitigation and adaptation to climate change in this mix of constraints.

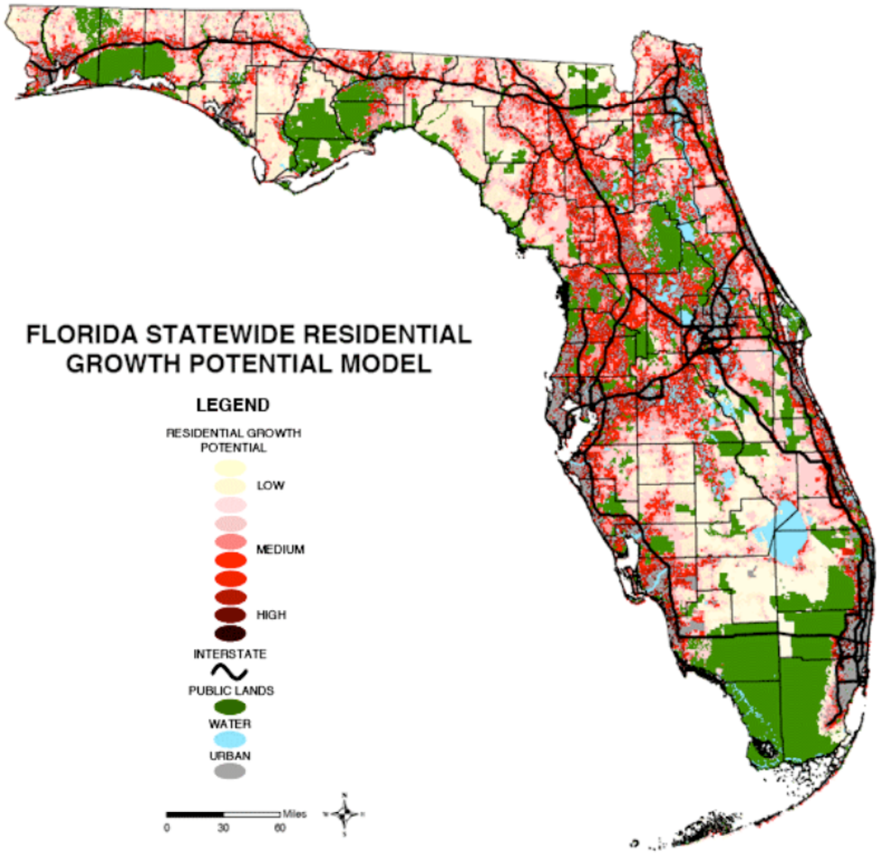


Figure 5. Florida growth potential by 2020. Data from J. Teisinger (University of Florida GeoPlan Center 2002)

Since the early 1800s, the history of Florida has been characterized by periodic land speculation, and over the last two decades the urban expansion of the state has been dramatic. Although recent declines in public school enrollment suggest that this growth may be slowing, given the large number of people of reproductive age, growth will continue to be high for the next few decades. Figure 5 shows the projected residential growth of the state by 2020 in which 2 to 3 million acres of aquifer recharge lands will be developed (estimated by the Florida Chapter of The Nature Conservancy). A recent study published by 1000 Friends of Florida shows that by 2060 an additional 7 million acres will be needed to support the growth rate measured through December 2005 (Zwick and Carr 2006). Forests cover about 15 million acres, and crop and pasturelands cover more than 8 million acres, of Florida's 34.3 million land acres (2002 data). By 2060, the projected urban expansion would consume 2.7 million acres from both agricultural and native habitat lands, respectively. As will be clear from the following discussion, this vision of the future is not consistent with either the goals of sustainable development or maximizing the opportunity for climate mitigation and adaptation through land management.

Land use change effects on regional climate

There is compelling evidence that not all climate change on a regional scale can be attributed to the atmospheric forcing effect of the GHGs. For example, conversion of tropical savanna to grassland has resulted in regional decreases in precipitation in South America, Africa, and Australia (McPherson 2007). A recent survey of California climate variability shows that about half of warming of the state since 1950 can be attributed to global warming through statistical association with increased Pacific Ocean sea surface temperatures. The remaining half of the warming can be attributed to land use change, with large urban areas exhibiting 2-5 times more warming than the state average (LaDochy et al. 2007). A similar pattern has been shown for the Eastern US (Kalnay and Cai 2003). The urban heat island effect does not account for all of the warming associated with land use change because changes in vegetation cover can significantly affect long wave and short wave emissivity, albedo (reflectivity), boundary layer thickness, potential evapotranspiration, and other factors contributing to local variation in temperature and precipitation (Pielke 2005; McPherson 2007; Waters et al. 2007).

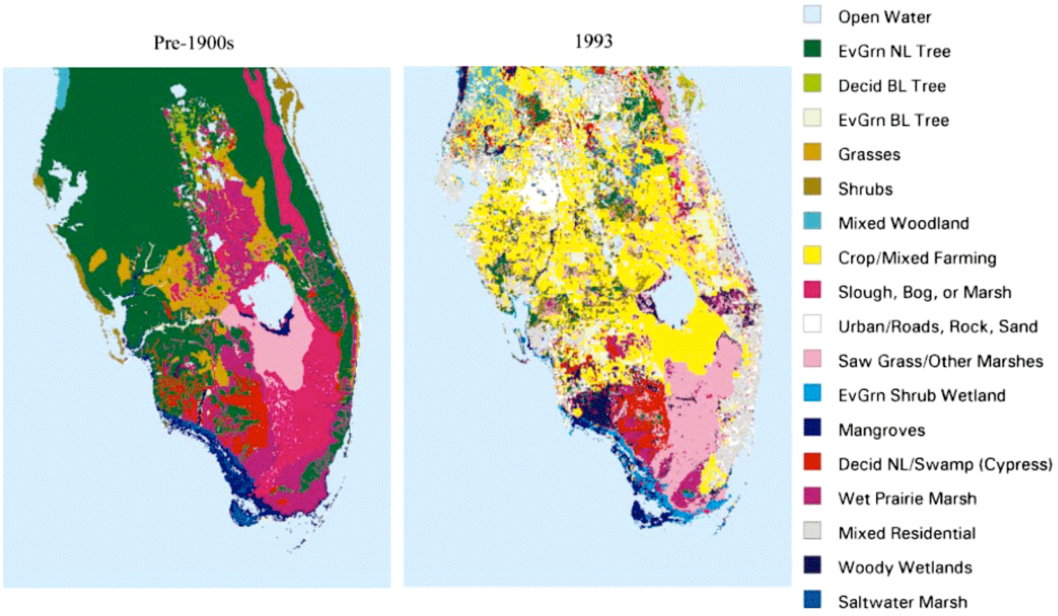


Figure 6. Land cover change between pre-1900 and 1993 for south Florida. Reprinted with permission from Marshall et al. 2004.

Exclusive of urbanization, Florida land cover has been altered extensively in the last century (Figure 6). While there has been a general trend toward higher mid summer maximum and minimum temperatures throughout south Florida, the draining of southern wetlands has resulted in an increased severity and frequency of economically damaging frosts for the region between Lake Okeechobee and the Everglades. This is plausible because the thermal inertia of intact wetlands retains heat in the lower atmosphere, while their loss allows dissipation of this heat overnight (Marshall et al. 2003). Similarly, changes in meteorological parameters (clear sky downward longwave radiation) have been associated with land use change in the subtropical climate of St. Johns River Water Management District in Florida (Rizou and Nnadi 2007). Unlike California, the entire of

Florida has not been surveyed for possible effects of land use change on regional (mesoscale) climate. It is likely that the effects of changes in vegetation cover on Florida climate have been extensive during the 20th century.

The urban heat island effect has increased dramatically for many of Florida's growing urban areas over the last century. Buildings, parking lots, roads and other paved surfaces of urban areas exhibit greater solar radiation absorption, greater thermal conductivity, and thus a greater capacity for releasing heat stored during the day overnight. Thus, urban areas tend to be warmer than surrounding areas in direct relation to the amount of impervious surface present in the landscape. In a study comparing the urban heat island effect in two metropolitan areas, the urban area of the Tampa Bay watershed was found to have a daytime heating effect, whereas the urban surface in Las Vegas showed a daytime cooling effect. These thermal effects are strongly correlated with urban development densities and percent imperviousness. Las Vegas may be cooler in part due to the tendency of the suburbs to become vegetated as the city has expanded, but overall there is a greater density of impervious surface in the metropolitan core of Tampa Bay relative to that in Las Vegas (Xian and Crane 2006). A strongly increasing heat island effect has been observed for the Miami metropolitan area as the city has grown, with the number of heat stress nights increasing by more than 24 days per year during the period 1950-1999. A similar trend has been documented for Tampa (Physicians for Social Responsibility 2001). The heat island effect has important implications for Florida energy use because for every 1^0 F increase in daytime temperature, as much as 225 MW (megawatts) additional power generation is required during periods of peak electricity demand in a large urban area.

Climatologists (e.g., Pielke 2005) have argued convincingly that land use change, including urbanization, should be considered a "first order" or primary forcing agent for mesoscale climate. For some regions over relatively short timescales, this effect can be greater than the climate forcing of the GHGs. Thus, the concept of heterogeneous forcing is the most appropriate paradigm for understanding climate change. The top-down approach inherent in the GCMs assumes that with sufficient model resolution we can accurately project climate many decades into the future. While this is a reasonable assumption for projections of globally averaged climate under the dominant influence of GHGs, it may not be true for regions on a shorter time scale as land use patterns change. Moreover, because the extremes of weather have important implications for human wellbeing, the average values derived from the GCMs can be misleading. Land use change often affects meteorological maxima and minima (e.g., Marshall et al. 2004). Based on current knowledge of the importance of land use for climate, it is appropriate that we use both a bottom-up and top-down approach when assessing climate change for a region. Climate models incorporating the GHGs, land use, and regionally relevant meteorological variables would be useful for predicting climate variability and change for regions the size of the state of Florida and smaller (Pielke et al. 2007). Ideally, mesoscale climate models would operate over timescales consistent with the rate of land use change and allow projections of how specific changes would affect climate. Although such models are being developed, significant resources are needed to advance this science, and there is an urgent need to assess land use impacts on climate given the rapid pace of urbanization of the state (cf. Zwick and Carr 2006).

Climate mitigation and adaptation overview

Climate mitigation and adaptation cannot be considered independently, and this is especially true with respect to land use. Adaptation to climate change in part depends on anticipating the speed of climate change, and thus plans for long-term adaptation depend on how aggressively we mitigate the causes of climate change. Land dedicated to mitigation through carbon sequestration can preclude, negate, or be synergistic with uses of the land for adaptation. For example, the design of sequestration projects must include consideration of the effect of land use change on regional climate (discussed above). Similarly, adaptation through strategic retreat of human populations from rising seas will consume some land that could otherwise be dedicated to carbon sequestration. The interdependency of these issues makes clear the need for comprehensive planning over a timescale of at least a century.

The Century Commission is charged with visioning sustainable solutions over a 25 and 50 year timeline, and thus our approaches to mitigation and adaptation must consider the implications for sustainability. How we achieve independence from fossil energy has enormous implications for progress toward sustainable resource use. Working Group III of the IPCC 4th Assessment (IPCC 2007) notes that sustainable development can reduce vulnerability to climate change, but climate change can slow progress toward sustainable development. Significantly, some energy alternatives to fossil fuels, such as very short-rotation harvest of timber for biofuel, are arguably unsustainable over the long term (e.g., depletion of soil nutrients and carbon) and should be viewed as transitional strategies or avoided altogether. How we develop these resources during the transition to a low carbon economy is of critical importance for the natural resources available to future generations. In contrast, many mitigation strategies are themselves tools for progress towards sustainability. Building design, community design, and strategies for minimizing fossil fuel use in transportation are central elements in strategies for reducing carbon emissions, yet these areas are also front line approaches for sustainable solutions for resource use.

Florida has yet to begin developing a portfolio of strategies for adaptation to climate change. While to some extent this depends on acquiring a better understanding of how Florida's climate may change over the present century, lessons can be learned from cases where past climate change has resulted in changes in natural systems and human economies. Easterling et al. (2004) provide a review of such examples for the US. Overall, it is clear that adaptation will not be a smooth or cost free endeavor. It will require substantial investments based on imperfect forecasts, and will be more difficult with greater and more rapid climate change. Typically, managed systems have fared better than natural systems, and there is significant potential for loss of Florida's biodiversity, especially in coastal regions subject to sea-level rise. Despite the economic risk of acting on imperfect foresight, proactive approaches are more likely to avoid or reduce damages than reactive responses. Areas for proactive adaptive strategies for Florida include (1) developing resilience in agricultural systems as they respond to changing growing conditions, (2) anticipating changes in species composition and productivity of forests, (3) enhancing watersheds and aquifer recharge capacity, and (4) developing strategies for retreat from rising seas while maintaining the integrity of coastal ecosystems. Below, I review the opportunities for mitigation in the agricultural and forestry sectors, while noting the implications for adaptation where appropriate.

The US greenhouse gas inventory and its biological components

The rise in GHGs in the atmosphere since pre-industrial times is mostly a consequence of emissions from fossil fuels at rates that exceed their biological uptake and degradation through physical processes. Thus, the first step in development of a state climate action plan is to construct a comprehensive GHG inventory, including Florida's landscape biological assets. The Florida Department of Environmental Protection (FDEP) will develop such an inventory over the next year. A GHG inventory provides estimates of anthropogenic GHG emissions sources and sinks and considers the most important anthropogenic greenhouse gases, which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6) perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). These gases have a wide range of radiative, or heat trapping ability once they are emitted to the atmosphere. Using CO_2 as the standard unit, the other greenhouse gases measured in an inventory have relative radiative forcing coefficients ranging from twenty-one for CH_4, to over three hundred for N_2O, to as high as twenty-four thousand for SF_6 when compared to an equivalent amount of carbon dioxide. CH_4 and N_20 are largely derived from biological systems. For accounting purposes and according to IPCC protocol, all gases are converted to a common metric known as CO_2, or carbon, equivalents (CO_2 Eq.) and expressed in teragrams (Tg or million tonnes).

Methodologies for GHG inventory are outlined by the US EPA Emissions Inventory Program, which is derived from the IPCC protocols (EPA 2007a). In all cases, the process requires the following steps: (1) obtain required data for the source of emissions, (2) estimate the total content of the GHG in the source, (3) calculate net potential emissions if all of the content were emitted, (4) estimate that fraction not emitted or sequestered and subtract from the total, (5) convert units to million metric tons of CO_2 equivalents, and (6) calculate total emissions. For transparency and portability the accounting system is based on a spreadsheet, and one such typical tool is the State Greenhouse Gas Inventory Tool (SIT). The SIT is divided into several source-based modules, and includes a synthesis module, which is used to compile emissions estimates and project emissions forecasts. Inventories typically focus on a temporal scale of 10 years (e.g., Michigan GHG inventory). The relative contributions of the Tier 1 GHGs (the most important GHGs; IPCC 2007) to the US profile are shown in Figure 7. Florida's last GHG inventory was completed in 1997, and thus an appropriate timescale for the next inventory should be from 1997 through 2007, assuming that our next inventory can be completed in 2008 or 2009.

GHG inventories are organized around the IPCC framework, which identifies five sectors:

- **Energy**: Total emissions from stationary and mobile energy activities; e.g., compiled from economic activity derived from state and federal records.
- **Industrial processes**: Emissions from industrial processes that are not associated with fuel combustion for energy; e.g., based on economic activity usually readily available from associated industries.
- **Agriculture**: Emissions from agricultural activities; e.g., estimates based on measures of agricultural activity.
- **Land use change**: Emissions and sequestration of carbon dioxide resulting from land use change, including forestry; e.g., extrapolated from estimates of GHG flux from acreage devoted to specific land uses.
- **Waste**: Emissions from solid waste and wastewater activities; e.g., derived from metrics maintained by municipalities.

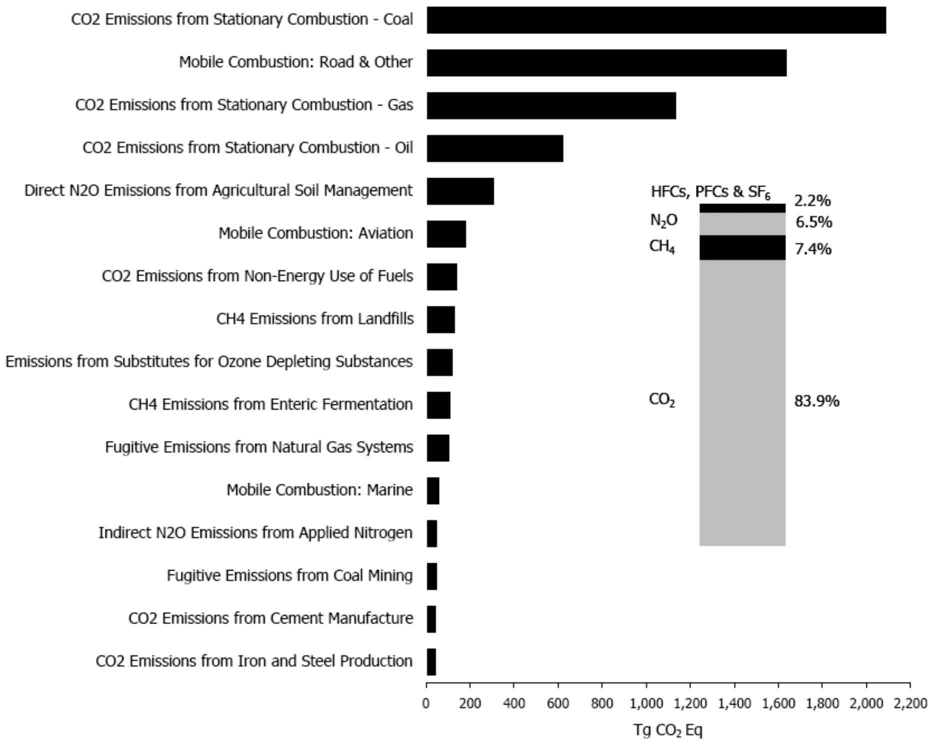


Figure 7. Tier 1 greenhouse gases sources and relative contributions. Taken from Figures ES-4 and ES-16, EPA 2007a.

Biological systems are a significant source of GHGs, but unlike fossil fuels, flux rates are harder to estimate because they are less tightly linked to records of economic activity. In addition to fossil fuels, CO_2 flux is also determined by photosynthesis and respiration and is thus linked to land use through forestry, agriculture, and natural ecosystems. CH_4 and N_2O are also variously derived from activities associated with agriculture and forestry. The sources of CH_4 and N_2O emissions are broken down more fully in Figures 8 and 9. Most US CH_4 emissions come from landfills, enteric digestion, and natural gas systems, and this is also true for Florida (Figure 8). Note that N_2O emissions from agricultural soil management and CH_4 emissions from landfills rank relatively low among the sources of all Tier 1 GHG emissions. The net contributions of US forestry and agriculture are shown in Figure 10. Through 2004, these sectors have resulted in a net carbon sink, with sequestration greater than CO_2 emissions from events such as forest harvest, land use change, or fire. Over 90 percent of the US carbon sink occurs on forested lands, offsetting over 12 percent of US GHG emissions. In contrast, agriculture is a net emitter of GHGs, producing over 6 percent of US annual emissions of CH_4 and N_2O. The net impact of forestry and agriculture in the US is a sink that offsets almost 6 percent of US GHG emissions (EPA 2005; revised figures for agriculture available from EPA 2007a). Enhancing this capacity is possible with appropriate management strategies discussed below.

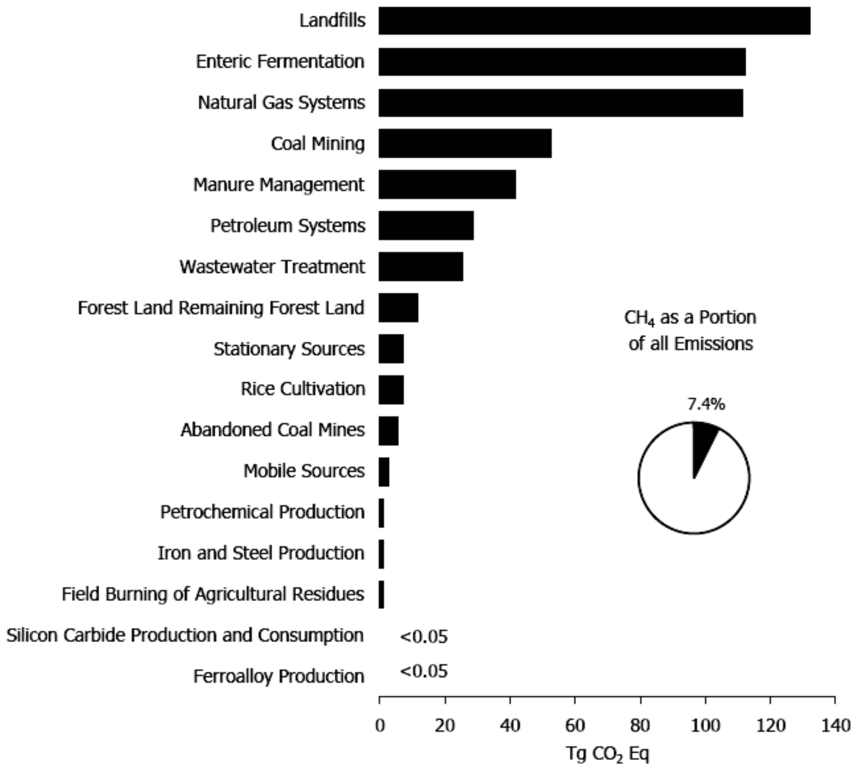


Figure 8. Methane sources for US. Taken from EPA 2007a, Figure ES-8.

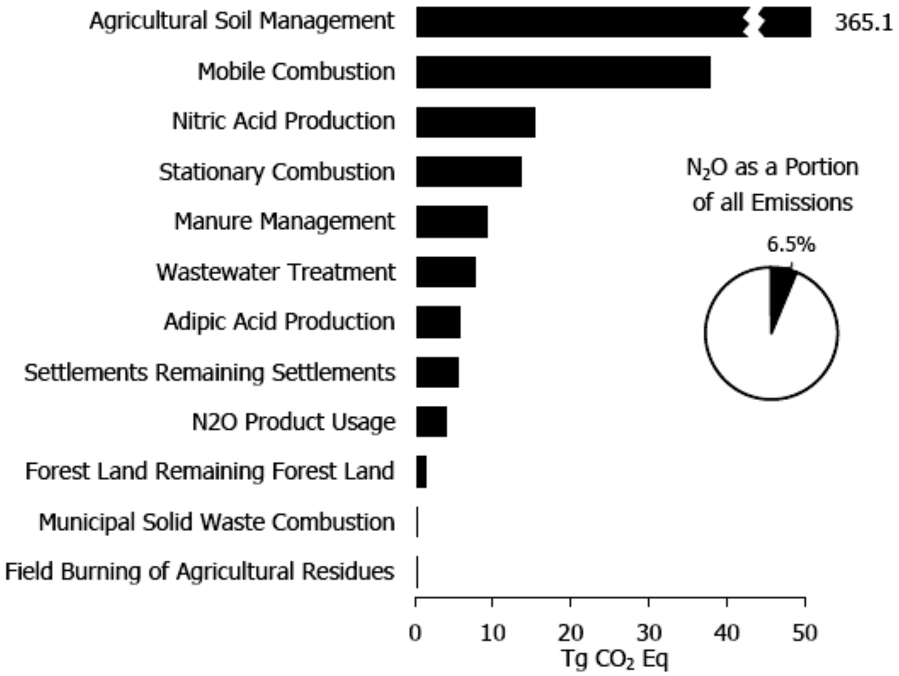


Figure 9. Nitrous oxide sources for US. Taken from EPA 2007a, Figure ES-9.

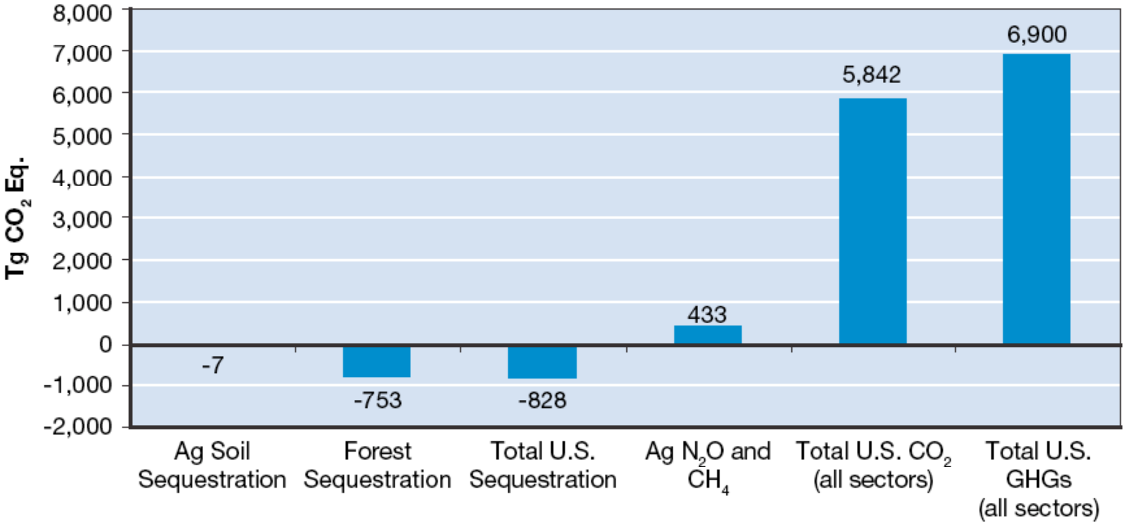


Figure 10. Forestry and agriculture net contribution to GHG emissions in the US, 2003. Total agriculture and forestry sequestration also includes urban trees, landfill yard trimmings and food scraps. Negative values represent a sink, positive values a source. (Figure 1-1 from EPA 2005)

Florida greenhouse gas emissions

Florida ranks sixth among the states in total GHG emissions, and is 30th among the world's top 75 emitters among states and nations (Center for Climate Strategies 2007). Florida produced 255.4 mmt (million metric tons) of CO_2 in 2004. From 1990 to 2004, Florida CO_2 emissions increased 37 percent, second in absolute growth only to Texas (Environment Florida 2007). Most of this increase in CO_2 emissions came from increases in the transportation sector, specifically gasoline consumption, while most CO_2 emitted was produced by power plants. Because 12 - 17 percent of Florida's electrical power comes from petroleum, its use for transportation and power generation make petroleum the largest source of CO_2 by fuel type, followed by coal and natural gas (DOE/EIA 2006; Elliot et al. 2007). Given the present trajectory, Florida's GHG emissions will grow by 88 percent by 2020, compared with 50 percent for the US as a whole (Center for Climate Strategies 2007). A 1997 GHG inventory conducted by ICF Consulting (Washington, DC) showed that similar to the US as a whole, the agricultural sector in Florida is a net emitter of GHGs while the forestry sector is a net sink, roughly balancing the emissions of agriculture in carbon equivalents. Overall, these fluxes are a small proportion of the total emissions from the energy sector. Florida has over 95 landfills, which are the largest source of CH_4 emissions in the state (FDEP). Some landfills, such as ones in Orange County and Alachua County, use this methane for power generation.

The implications for land use and development of carbon markets in Florida through using our natural landscapes, forestry, and agriculture for mitigation are significant. Although the GHG sources and sinks in the forestry and agriculture sectors of Florida are minor portions of the total emissions profile (Figure 10), they represent the greatest potential for offsetting and mitigating the projected increases in fossil emissions over future decades. This argument is compelling only if fossil fuels are displaced through the use of biofuels and biomass, and sequestration of carbon is substantial and long term. With worldwide CO_2 emissions rising at a rate of 1.6 - 2.5 percent per year (IPCC 2007), management of forests and agricultural lands could provide a highly effective tool for stabilization of GHGs in the atmosphere. The opportunity for mitigation provided by forestry and agriculture varies regionally throughout the US, but there is especially great potential in the southeastern US because of extensive forestlands and the opportunity to use biomass and biofuels as energy sources (EPA 2005). In 2002, forests covered 42.6 percent, and crop and pasture lands covered 24.5 percent, of Florida's 34.3 million land acres. By 2002, forested land in Florida had dropped by 35.9 percent from a high of 22.8 million acres in 1945, while the area occupied by urban lands increased by 3.4 million acres, or 672 percent. In contrast, during the same period, crop and pasture lands increased by 21.7 percent (USDA/ERS 2006).

Florida agriculture and climate mitigation

Agriculture in Florida can play an important role in mitigation of GHGs through increased carbon sequestration in agricultural soils, production of feedstock for biofuels, and management of agricultural wastes, especially manure. Although agriculture is presently a net producer of CH_4 and N_2O (Figures 8 and 9), proper management for sequestration, emissions reductions, and offsets holds the promise of significant reductions in this source of atmospheric GHGs. With almost a quarter of Florida's landscape devoted to agriculture, carbon markets could provide an important new revenue stream for farmers. Present land values often reflect development potential, which exceeds the value of the land for production of crops and livestock. Driven by the economic value of agricultural lands for climate mitigation, carbon markets could significantly alter this equation in favor of keeping lands in production, slowing the rate of urbanization in Florida.

Carbon sequestration in agricultural soils. The warm and moist conditions of the southeastern US support high annual C fixation in plant biomass, while promoting high rates of decomposition (Franzluebbers 2005). Under present practice, agricultural soils in the US sequester a relatively small amount of carbon (Figure 10), and are responsible for almost 70 percent of US N_2O emissions (Figure 9). Depending on management, soil carbon storage (topsoil and subsoil) in Florida likely follows the general trend: wetlands >> pinelands > rangeland/grassland ~ urban > improved pasture > upland forest > cropland. On average, Florida ranks highest among all US states in terms of soil organic carbon content (Guo et al. 2006). Regardless, Florida agricultural soils are frequently sandy and can have low organic content partly because warm temperatures and high precipitation lead to rapid breakdown and leaching of organic compounds (Grunwald 2007). Soils in the Southeast, including Florida, have experienced enormous erosion and loss of carbon stocks during the 19th and 20th centuries largely as a consequence of conventional tillage practice (Franzluebbers 2005). Coastal regions of Florida typically contain more soil organic carbon than the interior of the peninsula, while the Everglades contain some of the highest concentrations of any soils in the US (USDA-NRCS 1997).

Despite the generally high soil organic carbon content of Florida soils, they have considerable potential to sequester additional carbon through appropriate management. Agricultural soils in Florida are not generally managed for enhancing carbon sequestration and reducing N_2O, and this is clearly an area with significant potential for mitigation. In general, all conventional tillage systems used in intensive agriculture result in significant net emissions of GHGs relative to late successional systems, suggesting the best practice should include no-till and removing marginal land from production (Robertson et al. 2000). Several tillage studies for the Southeast show that no-till or conservation tillage increases crop yield and carbon sequestration, while reducing the need for nitrogen fertilizer over a period of 5 to 12 years. Increasing the cropping complexity to include rotations of plants capable of nitrogen fixation can enhance the fertility of the soil, and this minimizes but does not negate N_2O release relative to conventional fertilization. There is little known about which specific mix of tillage, fertilizer application, and crop rotation would work best for enhancing carbon sequestration in Florida soils, but past studies demonstrate that these regional differences can be understood, producing recommendations for best practices (reviewed by Franzleubbers 2005). A more complete understanding of GHG emissions from Florida soils and the potential for mitigation depends on gathering data on the impact of various agricultural practices. Such data are necessary before Florida agriculture can be properly integrated into emerging carbon markets.

Biofuels. The 8.4 million acres of Florida crop and pasture land represent an opportunity for agricultural production of biofuels. In theory, production of ethanol or biodiesel from crops could provide a "carbon neutral" source of fuel because emissions from the use of biofuels are offset by photosynthesis during ongoing production of biofuel crops. In practice, the lifecycle carbon emissions including fossil fuels used in production and transport must be known in order to assess the net effect. Figure 11 shows the lifecycle GHG emissions from various alternative fuels (EPA 2007b). For ethanol produced from corn and refined in Florida, these emissions would be considerable because Florida has only modest corn production compared to other states. Thus, corn-produced ethanol should be purchased from facilities close to the source of the corn for this to be an effective greenhouse gas mitigation strategy. In the best-case scenario, corn produced ethanol reduces greenhouse gas emissions by 13 to 23 percent relative to petroleum (Farrell 2006; EPA 2007b). If transported long distances and produced in refineries fired with fossil fuels, use of corn ethanol can actually produce more greenhouse gases than petroleum (Farrell 2006). In principle, sugar cane holds the greatest promise in Florida for ethanol production directly from fermentation of carbohydrates. Florida has extensive sugar cane, sorghum, and citrus by-products that could be diverted to this process, but current market values and subsidies make development of these resources unlikely. Biodiesel derived from transesterification of vegetable oil from soy, peanut, sunflower and rapeseed also represents a significant opportunity for GHG reduction (Figure 11), but the potential of biodiesel for Florida agriculture is mostly unexplored (Hodges 2007).

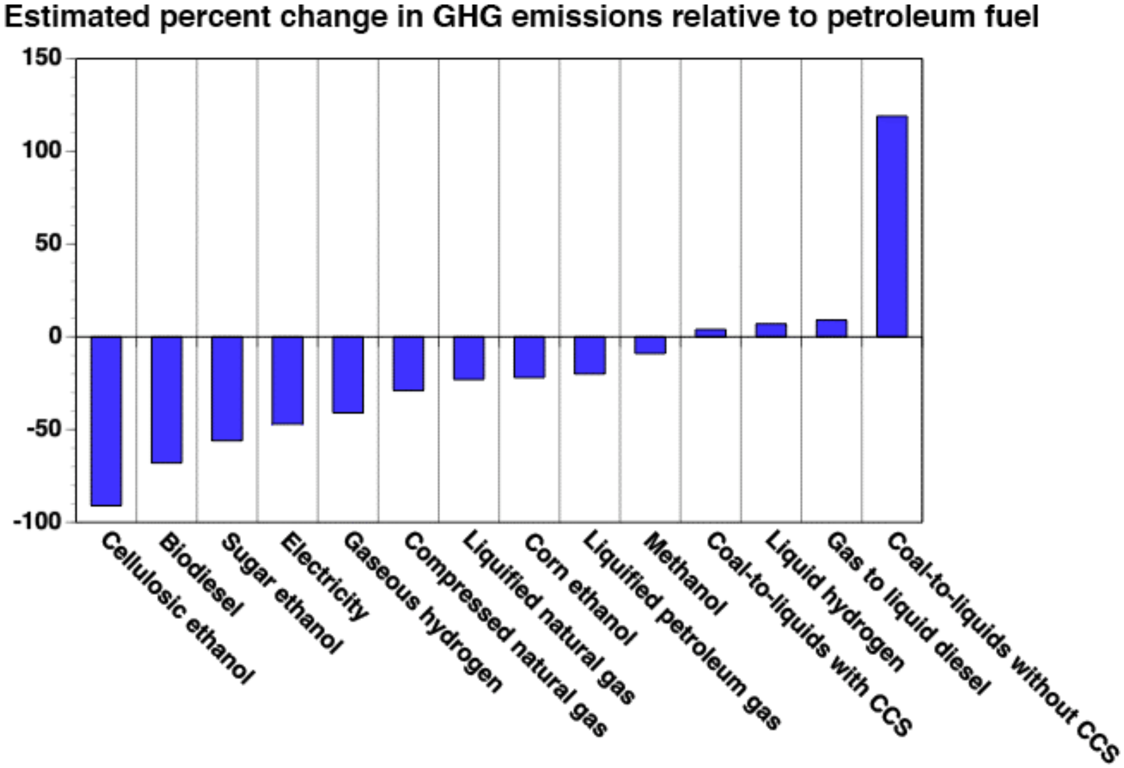


Figure 11. Lifecycle GHG emissions from various alternative transportation fuels relative to GHG emissions from petroleum fuel (EPA 2007b).

By far the most favorable yield with respect to GHGs comes from the use of cellulose (the woody or lignified parts of plants) to produce ethanol (Figure 11). Production of cellulosic ethanol results up to 88 percent reduction of greenhouse gases even when fossil carbon used in production and transport is included in the accounting (Farrell, 2006; EPA 2007b). Florida has significant biomass resources for the production of cellulosic ethanol from wood, crop wastes, and fast growing, high cellulose crops. Presently the University of Florida is creating a production facility to demonstrate the feasibility of cellulosic ethanol, and most experts suggest that we are several years from full-scale mass production (Hodges 2007). Environmental concerns with respect to production of ethanol from carbohydrate or cellulose include the large amount of water necessary to process the biomass.

Management of livestock wastes for biogas production. Livestock wastes produce CH_4 and N_2O, both potent GHGs, and manure management is a significant source of the total US emission profile for these gases (Figures 8 and 9). Although methods to reduce N_2O emissions from livestock wastes are not well developed, Florida has significant potential to generate power from biogas (CH_4) derived from waste at agricultural operations, especially feedlots. The advantage of this for reducing greenhouse gas emissions is threefold. First, this waste generally embodies recently fixed carbon rather than fossil carbon, and thus over a time frame of decades does not contribute to a net increase in atmospheric CO_2. Secondly, power generation from waste consumes methane, itself a greenhouse, which would otherwise be liberated to the atmosphere. The resulting products of combustion add less CO_2 than the coal required for an equivalent amount of energy. In addition, production and use of biogas from manure avoids those GHG from fossil fuels that are displaced through biogas use.

Fig. 12. Fixed-film anaerobic waste digester for methane production at the University of Florida. Photo courtesy of A. Wilkie.

Florida 's livestock inventory in 2004 included 26 million poultry, 1.5 million beef cattle, 500,000 horses, 140,000 dairy cattle, 100,000 swine, 30,000 goats, 10,000 sheep, and millions of companion animals (Florida Department of Agriculture and Consumer Services). A significant technical challenge for biogas production in Florida is the large quantities of water-flushed dilute manure waste typically produced by dairies and feedlots. Fortunately, biogas can be produced in fixed-film digesters recently developed at the University of Florida (Figure 12) designed to handle dilute waste. In contrast, methods for producing biogas from dry waste are well developed and have been demonstrated commercially on a limited basis. Estimates of fossil CO_2 displaced by biogas total about 0.4 Tg CO_2 yr^{-1} for Florida dairy cows, poultry layers and poultry broilers. While the opportunity for on-site power generation can provide financial incentive for Florida farmers, additional incentive derives from the sale of carbon credits on the carbon market, which could total more than $62 million at a value of $4 per Mg CO_2 Eq for dairy cows and poultry (Wilkie 2007).

Florida forests and climate mitigation

Forests in the US were in approximate carbon balance with the atmosphere from 1600-1800. Harvest and human development caused a large release of carbon emissions from forests during the 19th century. Forest regrowth has resulted in significant net sequestration of carbon, and presently US forests sequester about 200 Tg CO_2 Eq yr^{-1}. Although recent data suggests that this rate is declining, proper stewardship using well-established practice could result in an additional 100-200 Tg CO_2 Eq yr^{-1} during most of the 21st century (EPA 2005; Birdsey et al 2006). In the Southeast, there was net loss of landscape carbon from 1900 until the 1940s, followed by net sequestration (Woodbury et al. 2006). Covering over 42.6 percent of the state, Florida forests are the largest landscape source of climate-mitigation capacity in the state, and thus they represent the greatest potential for the state's long-term participation in carbon markets. Figure 13 shows the management type and land ownership as a percentage of forest cover in Florida. Approximately 80 percent of Florida forests are under private ownership, and this has important implications for the management of forestlands for climate mitigation.

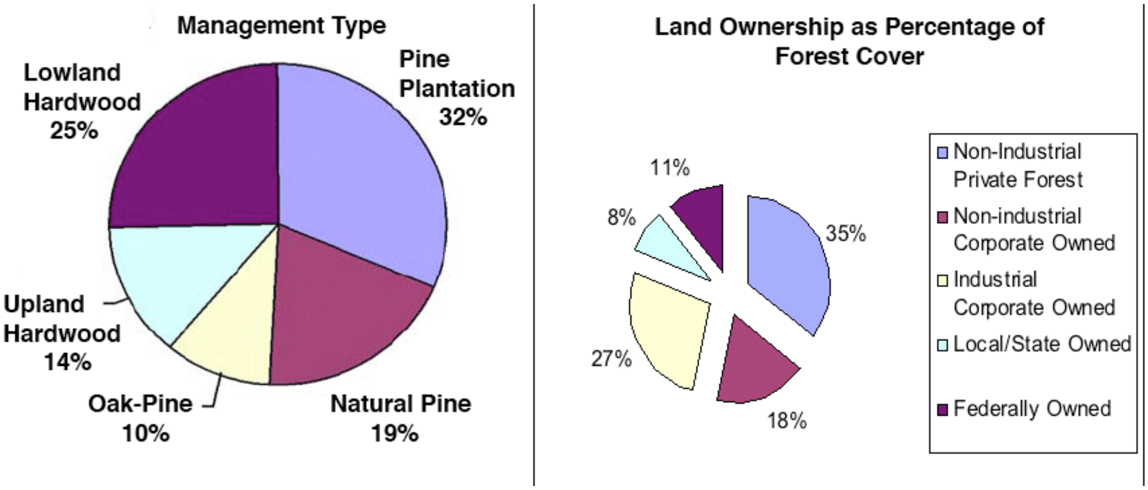


Figure 13. Florida's forests by management type and ownership (Source: Carter and Jokela 2003)

In situ carbon accumulation begins immediately after disturbance and continues through maturity for temperate and tropical forests, while the age at maturity is dependent on the species and local conditions (Figure 14, adapted from Pregitzer and Euskirchen 2004). Throughout this process, carbon sequestration through forestry is influenced by three factors: (1) carbon stored in standing biomass, (2) carbon stored below ground; and (3) carbon stored in forest products (Johnsen et al. 2001). Management of forests for carbon sequestration requires the construction of carbon budgets for each of these components in which gains and losses during growth, harvest, and uses of forest products is quantitatively assessed. Although this accounting process requires extensive data and tracking of GHG inputs and outputs, it is relatively straightforward for a given mitigation project. Complications to the accounting system are discussed below with respect to the concepts of reversal and leakage.

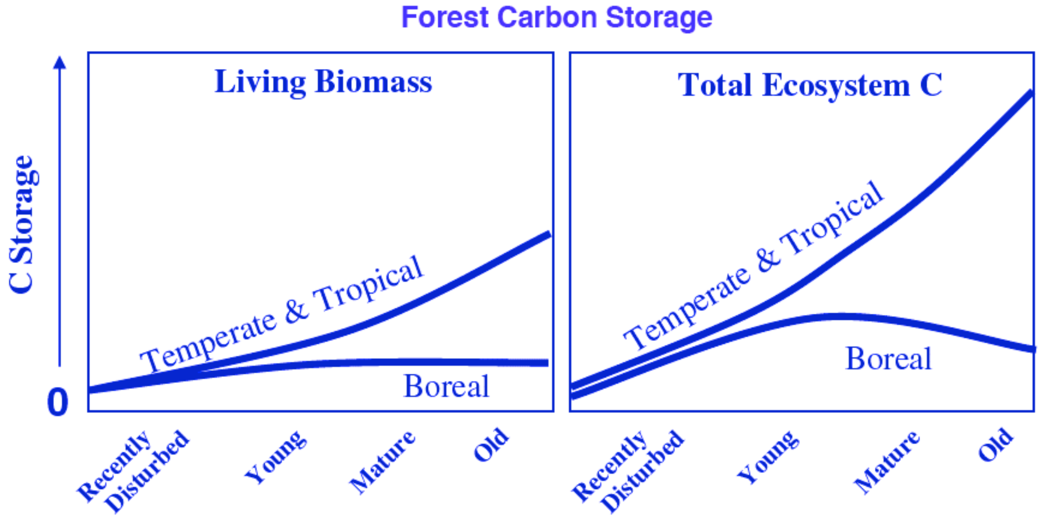


Figure 14. In situ forest carbon storage for forests from different biomes. Adapted from Pregitzer and Euskirchen 2004; Birdsey et al. 2006).

Displacing fossil fuels with woody biomass. Besides direct sequestration, forests provide the opportunity for avoiding the use of fossil fuels if wood is used for fuel and other products that are derived from the use of fossil fuels. As with biogas, woody biomass embodies recently fixed carbon and, assuming that forests are replanted or continue growing after harvest, its use will not contribute to a net increase in atmospheric CO_2. Figure 15 shows the theoretical cumulative fossil-carbon emissions avoided through a short-cycle cutting and replanting scheme with sequential growth and harvest of woody biomass products for energy, short-lived products, and long-lived products (Cushman et al. 2007). This idealized scenario assumes a high growth rate and high efficiency in the use of fuel wood. It is important to realize that because of the short-cycle rotation, this forest does not sequester more carbon than it loses through harvest (the trees and products are below the zero line), and the carbon savings are realized entirely by reductions in the use of fossil fuels. Note also that additional reductions of fossil fuels can be realized if short-lived and long-lived products are used in lieu of some products created through the use of fossil fuels (e.g., replacement of steel framing with wood framing in construction).

The rate of accumulation of carbon in forest and the amount of fossil fuel displaced is highly dependent on the growth rate of the trees. For example, fast growing species such as Poplar (*Populus deltoides* L.) could be harvested in 50 years (Cushman et al. 2007), while commercial pine plantations of Florida could be cut and replanted on a cycle of about 25-30 years, depending on management intensity (Alavalapati 2007). In order to realize the potential for Florida forests for climate mitigation, carbon budgets such as the one shown in Figure 15 must be constructed for each management scenario on a site-specific basis. It may be that slow-growth hardwood forests are more valuable with respect to mitigation for their long-term carbon sequestration, rather than fuel wood production.

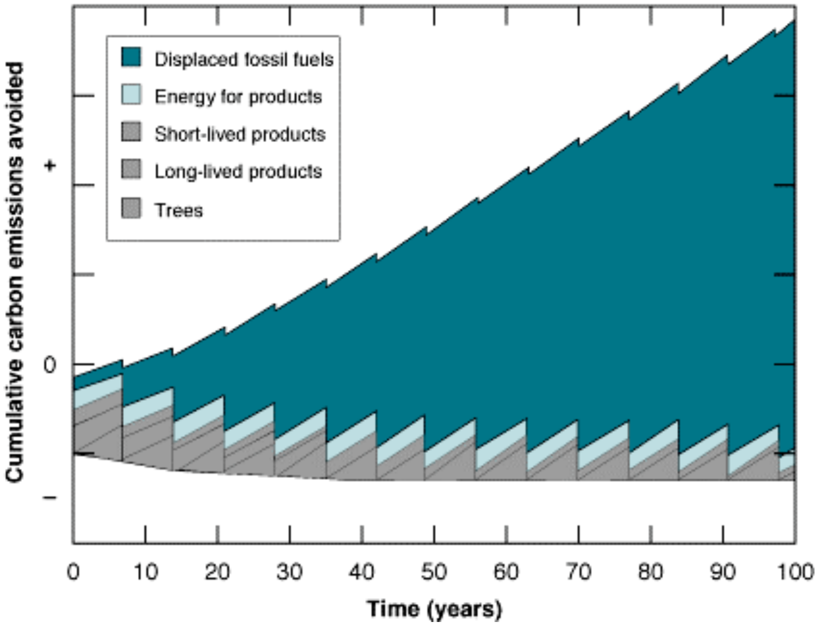


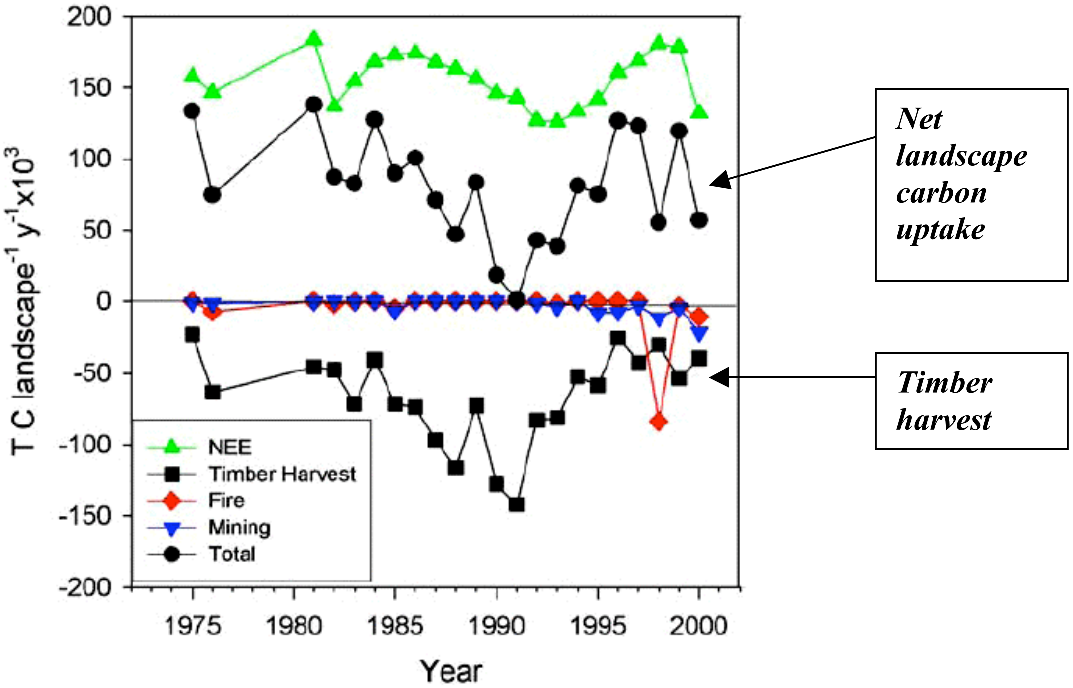
Figure 15. Fossil emissions avoided during sequential growth and harvest of forest products for energy, short-lived products, and long-lived products. Some carbon is lost from soils, as reflected in the drop in the bottom line of the figure (Cushman et al. 2007).

The economics and pollutant profile of using wood to replace coal are favorable. A recent analysis (M. Langhotz, University of Florida) shows that at $3 per million Btu (a price competitive with coal), woody biomass could supply about half the power produced by a medium size power plant for one year for the region around Green Cove, FL. If the timber and waste wood were used, such a plant would require somewhat less than 200,000 acres, equivalent to a forest with a 10-mile radius. Moreover, wood from forests can be used to fuel boilers at coal-fired power plants with minimal modification. Retrofitting of scrubbers would be required for proper control of particulate and aerosol emissions. A comparison of emissions from wood and other fuel sources is shown in Table 1. Significant environmental concerns with the use of woody biomass for fuel include the potential for large-scale land conversion to non-native species, the fact that industrial forests are prone to fire, and the emissions from fossil fuel used in production and transport.

Pollutant	Woody biomass	Coal	Heavy oil	Natural gas
Sulfur dioxide (lbs/ton)	0.08	39	157	
Nitrogen oxide (lbs/ton)	1.5	21	47	
Carbon dioxide (lbs/million Btu)	0*	225	174	117

Table 1. Net emissions of electric power plants - comparison of biomass and fossil fuels.
*Source: DOE/EIA, Power Technologies Data Book, 2003. *Assumes a source of woody biomass as recently fixed carbon and that forests will be replanted or continue to grow. Note that this does not include fossil fuel used in production and transport of woody biomass. Table courtesy A. Hodges, University of Florida.*

Positive net carbon sequestration by managed forests. While direct combustion of woody biomass holds great promise for displacing coal in power plants in Florida, it is also possible that properly managed industrial forests can provide net carbon sequestration on a landscape basis. A recent study by scientists at the University of Florida indicates that industrial forests of the southeastern US can be used for fuel wood while also maintaining significant net carbon sequestration (Binford et al. 2006). Direct measurements of landscape gas exchange show that these forests continue to sequester substantial carbon when under mild harvest intensity (Figure 16).



Net landscape carbon uptake

Timber harvest

Figure 16. Total landscape carbon flux per year for four forests in the Southeast. NEE is the net ecosystem CO_2 exchange, and mining refers to phosphate mining. Values above zero indicate positive landscape uptake while values below zero indicate carbon loss. Total indicates net landscape sequestration (Binford et al. 2006).

Climate mitigation through afforestation. Carbon credits derived from afforestation and tree planting are currently traded on carbon markets, and forests are touted as a major source of carbon offsets. Moreover, there is clear evidence that afforestation of agricultural lands can provide significant ecosystem carbon sequestration (Morrris et al. 2007). As discussed below, use of carbon offsets will lead to meaningful reductions in GHGs only if significant absolute reductions in fossil emissions occur and the carbon budget accounting of forest carbon sequestration is comprehensive. An added complication is that recent science has raised issues about the global energy balance of afforestation. One possible non-GHG effect of widespread afforestation in the US is that this activity may actually warm the atmosphere, despite the increased carbon sink provided by such forests. GCMs indicate that global replacement of current vegetation by trees would lead to mean global warming, while replacement by grasslands would result in cooling (Gibbard et al. 2005). This effect is largely due to the diminished albedo of snow cover in forested lands in the mid to high latitudes during the winter months, while models show that afforestation in warm latitudes would be clearly beneficial in mitigating global-scale warming (Bala et al. 2007). Because evapotranspiration removes heat efficiently from the surface under warm temperature at low latitudes, a cooling effect should dominate in the warm forests of Florida where there is little or no opportunity for snow cover. Accordingly, afforestation is an appropriate climate mitigation activity for Florida, but needs to be carefully evaluated through construction of landscape radiant energy budgets for more northern regions of the US. It is thus possible that carbon offsets from Florida forests will have a competitive advantage in carbon markets because they are more tightly linked to climate mitigation than are forests in more northern latitudes.

Florida wetlands and climate mitigation

Wetlands must be part of any carbon accounting of Florida because of their extensive surface area, large soil carbon pools, high CH_4 emissions, and gross potential for carbon sequestration. US wetlands may be a small to moderate carbon sink of about 49 Tg CO_2 Eq yr^{-1}, but there is considerable uncertainty associated with this estimate because of losses of soil organic carbon through fire and drainage, and CH_4 emissions from functional wetlands (Bridgham et al. 2006). Historical reductions by at least 50 percent of Florida wetlands have resulted in significant losses of soil organic carbon and, as noted previously, radiative forcing of local climate (Marshall et al. 2004). The Everglades cover about 6 percent of Florida's land area and contain some of the largest stocks of soil organic carbon per area in all of North America (USDA-NRCS 1997). As the Everglades continue to be degraded through failure to maintain appropriate seasonal water flows (hydroperiod), an unknown amount of this carbon is being lost. Overall, it is uncertain how anthropogenic climate change will affect Florida wetlands, but it is clear that we can reduce losses of carbon stocks by maintaining hydroperiod and controlling the extent of wildfires during dry periods. Note that prescribed burns are necessary for the health of this and other ecosystems in the state. Management to reduce wetland emissions of CH_4 is impractical and inconsistent with keeping these ecosystems intact (Bridgham et al.

2007). Statewide, wetland mitigation and banking procedures can be reviewed to determine the potential for net GHG emissions associated with this practice.

Opportunities for sustainable land use through carbon markets

Emissions regulatory systems being developed throughout the world rely primarily on some form of cap-and-trade mechanism and carbon credits traded on carbon markets. Such a mechanism caps the total emissions permissible from regulated activities, and emitters can comply by (1) improving efficiency, (2) purchasing allowances from other emitters who are below their regulated limit, and (3) by purchasing carbon offsets from enterprises that remove GHGs from the atmosphere. Forestry and agriculture are by far the most important sectors for creation of offsets, but natural landscapes could also play a role. While trading allowances have been developed based on this potential, they frequently omit significant components of reversal and leakage (discussed below). This lack of total accountability has called into question the effectiveness of the cap and trade system and makes clear the need for comprehensive assessments of GHG flux over time and space.

Mitigation scenarios are based on carbon market drivers as well as the markets for forest and agricultural products. The current state of the art is represented by the model employed by the US EPA known as the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG; EPA 2005). This is a partial equilibrium economic model of US forest and agricultural sectors, with land use competition and linkages to international trade. Another example that is perhaps more applicable to regions such as Florida is the Integrated Assessment Model developed by McCarl and colleagues (e.g., McCarl & Schneider 2001). This model portrays farmers choices across regions among a set of crop and livestock management options including tillage, fertilization, irrigation, manure treatment, and feeding alternatives. At the heart of this exercise is the market price of carbon equivalents, which is used to model future impacts of mitigation. An example of the outcome of one such modeling effort is shown in Figure 17. Although a carbon market based on voluntary caps exists in the US, forestry and agriculture in Florida have yet to participate in any meaningful way. It is arguable that mandatory federal caps will be necessary for such markets to have a significant role in GHG management.

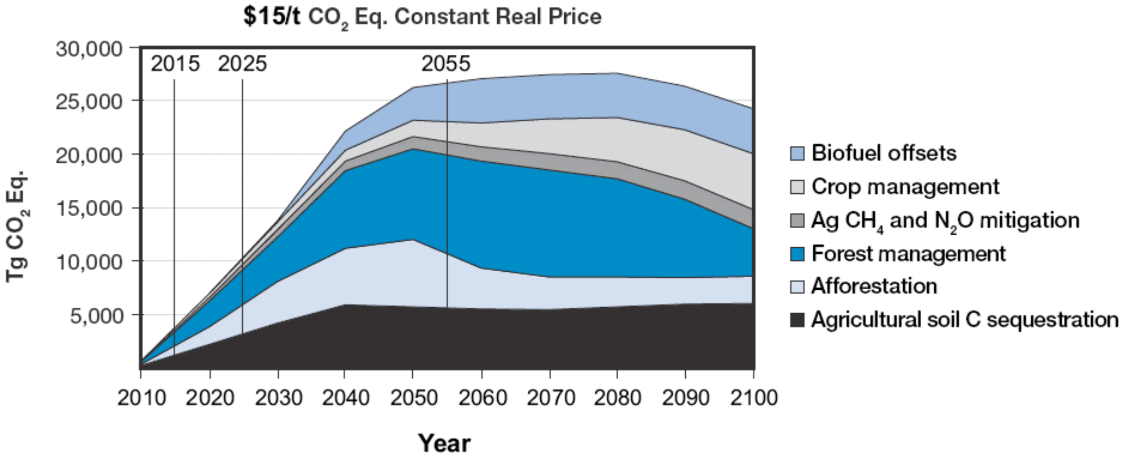


Figure 17. Cumulative GHG mitigation potential over time as an example of output from FASOMGHG. Reproduced from Figure 4-6, US EPA 2005.

Using managed and natural ecosystems for GHG mitigation requires an understanding of the dynamics of their GHG flux. Quantification of the time-specific carbon budget of these biological systems is an essential first step, but it does not account for all GHGs associated with a mitigation project or the changes in the carbon budget over time. For example, under a given practice, soils can become saturated with carbon over time, and thus GHG management must account for this likelihood. Similarly, the GHG advantage provided by biofuels must account for fossil fuels used in the production and distribution of energy crops. Understanding these dynamics is a complex economic and ecological analysis that requires quantification of markets, incentives, and mitigation targets over the time frame which mitigation should occur. Always embedded in this analysis is a market value for quantities of GHG mitigated per unit time (discussed below) expressed as carbon equivalents. Two concepts help define the caveats associated with mitigation projects – reversal and leakage.

Reversal. Reversal refers to the loss of sequestered carbon if it is re-released into the atmosphere at some future date. Typically, most biological systems capable of sequestering carbon will exhibit a slowdown of carbon capture until an equilibrium point, or saturation, is reached. Soils can become saturated with organic material, and some temperate zone, fast-growing forests will approach maximum net sequestration at about 80-100 years following afforestation. A disturbance such as a forest fire or significant clear-cutting with associated burning can cause reversal for forestlands. Fires and inappropriate hydroperiods are an ongoing significant source of reversal for the Everglades, one of the largest pools of sequestered carbon in the US. Soils may exhibit reversal when placed under intensive tillage as opposed to conservation tillage or no-till practice. Table 2 below shows the qualitative risk of reversal of GHG benefits for various aspects of forestry and agriculture. Not included in the consideration of reversal is the fate of carbon embodied in long-lived products after the time of harvest. Given that stabilization of the climate system is an intergenerational enterprise, embodied carbon must ultimately be quantified in the analysis of the potential for mitigation. Note also that mitigation through biofuels and agricultural CH_4 and N_2O are permanent emissions reductions to the extent that they do not involve carbon storage and are not subject to reversal. This assessment is generally valid only if biofuels are used to permanently displace fossil fuels, and croplands for growth of fuel crops are managed to reduce loss of carbon from the soil.

Activity	**Potential**	**Risk of reversal**
Afforestation	High in most places within US	Moderate if timber or land prices change or natural disturbances (fire, pests)
Forest management	Carbon budget analysis necessary to demonstrate the value of alternative practice	Moderate if timber or land prices change, or natural disturbance (fire, pests)
Protection (avoided deforestation)	High if current rates of deforestation are high	Low if legal protection is enforced. High if susceptible to wildfire, has uncertain legal status, or major commodity price change, etc.
Agricultural soil carbon sequestration	High if alternative tillage is adopted and maintained	Moderate to high: potential seasonal tillage change (e.g., weed control); or change in crops or tillage practices in response to commodity prices or programs
Agricultural CH_4 and N_2O mitigation	Moderate to high, assuming emissions per unit production data are known. Requires known changes in management practice	Low or none. No carbon storage subject to re-release involved.
Biofuels offsets	High based on recent market trends in fuels.	Low or none. Primary benefit does not involve carbon storage subject to re-release, although response to market prices could affect soil carbon.

Table 2. Qualitative consideration of potential and risk of reversal for activities in the forestry and agricultural sectors. (Adapted from Table 6-6 US EPA 2005)

Leakage. Leakage refers to goods and services derived from processes that have released GHGs and are imported from outside the boundaries of a mitigation project. Thus, the GHG mitigation benefits of a project can be diminished by leakage. Leakage is calculated as a proportion of the direct GHG reductions achieved by the targeted activity diminished by indirect GHG emissions from the non-targeted activity, and this value needs to be assessed over a timeline appropriate to these activities and the market drivers (EPA 2005). For example, ethanol produced from corn transported long distances by conventional trucks or trains to coal-fired refineries can actually result in more net GHG emissions than petroleum (Farrell 2006). Similarly, afforestation without accounting for GHGs emitted by associated activities can decrease the GHG mitigation potential by more than 20 percent (EPA 2005). Leakage can result also when market forces affect a mitigation project. For example, afforestation of the South-Central US, could cause significant land use change in the southeastern US (e.g., a shift to more acreage in agriculture), resulting in additional GHG emissions from this region. The most important point from analysis of leakage is that all internal and external activities associated with a mitigation project must be included in the GHG mitigation analysis. In order to minimize these unintended consequences, policies and incentives for mitigation must be comprehensive. Development of such comprehensive plans requires a thorough knowledge of market interdependencies and drivers as well as the carbon budgets of the managed biological systems.

Non-GHG effects of mitigation. Mitigation efforts using biological systems can have large non-GHG environmental co-effects with perceived positive or negative value. Even at a low GHG price, changes in land use and production can induce positive changes in tillage practice and promote carbon sequestration, while reducing erosion and nutrient runoff (EPA 2005). Control of weeds without tillage, however, may result in the negative co-effect of increased herbicide use and associated toxic runoff. Alternatively, large-scale conversion of agricultural lands to forest may have positive effects on water and air quality. One negative effect of producing energy crops is the creation of extensive tracts devoted to non-native species such as Elephantgrass (*Pennisetum purpuretum* L.) or Spanish cane (*Arundo donax* L.). Similarly, ethanol production can require enormous quantities of freshwater, placing a strain on regionally scarce water resources. The co-effects of GHG mitigation on biodiversity may be both positive and negative, depending on location and mitigation activity. For example, industrial forests typically have lower biodiversity than natural or semi-natural forests, but higher diversity than crop and urban lands. These high-density forests tend to be more prone to reversal through wildfire than natural forests.

Ecosystem service valuation through carbon markets. The profound implication of incorporating biological systems into carbon markets is that this represents the first step toward reconciling the planet's living carbon economy with its monetary economy. If carbon markets are truly comprehensive and implement honest accounting including reversals and leakages, they can begin to provide a common denominator for economic valuation of ecosystems and many of their associated services. To the extent that the practice of GHG mitigation results in enhancement of these ecosystem services, carbon markets can facilitate the development of sustainable resource and land use. As these markets are implemented, nature's goods and services will increasingly cease to be treated as externalities in the human economic system. Because Florida has yet to begin the carbon accounting of its biological systems, the opportunity exists to take the first bold steps toward creation of a powerful new economic means of promoting sustainable practice across a broad array of human activities.

Overview of creating, measuring and verifying Florida GHG offsets

Florida has tremendous potential for the creation of landscape GHG offsets with properly managed forest and agricultural lands. Critical to the creation of offsets is the process of quantification, validation, and determination of ownership. The following describes this process in overview, as detailed in a recently published manual from the Nicholas Institute for Environmental Policy Solutions (Willey and Chameides 2007). The necessity of validating offsets suggests that a proper role of government is to provide oversight and certification of those businesses and industries that will service the carbon-offset market.

Creating offsets. Offsets are created in a series of steps. Project managers must first define the land-management practices they will use to create offsets, and then establish the spatial and temporal boundaries of the project. Estimating the boundaries of a project allows developers to scope the costs and benefits to reasonably determine whether the net offsets will justify probable costs. In order for an offset to be valid and marketable it must be additional. That is, any reductions in GHG emissions or increases in stores of carbon would not have occurred without the project. Determining **additionality** is a complicated and critical effort in determining a project's net GHG benefit. This is accomplished by estimating the difference between GHG emissions from lands and facilities during a project and a designated baseline. The baseline consists of comparison lands similar to and near project lands or, in some cases, a small fraction of project lands or facilities where project activities are not implemented. In calculating the net GHG benefits and estimating leakage from the project, the GHG offsets that are produced can be estimated.

Measuring offsets. Developers need a monitoring and quantification plan before beginning a project to ensure a project's offsets are verifiable and satisfactory to buyers and regulators. The most important part of this plan lays out the methods used to monitor changes in GHG emissions or carbon stocks resulting from the project's land-management practices. Therefore, proficient monitoring crews are crucial in determining a project's net greenhouse benefits. Monitoring crews should accurately sample the project's GHG impacts at appropriate locations and frequency, and within an appropriate timeframe. The techniques used to measure net changes in emissions and sinks will depend specifically on the type of land-management project. These measurements are then used by quantifiers to calculate carbon offsets claimed by project developers, taking either the total stock of carbon stored on project lands (carbon sequestration) or total GHG emissions from project lands (emissions reduction), baseline measurements and leakage into account. Quantifiers must also account for uncertainty because as uncertainty rises, regulators of a capped system will generally accept a smaller proportion of offsets as real. Developers can optimize their profits by balancing acceptable levels of uncertainty and operating costs.

Verifying offsets. When a qualified, independent party verifies a project's offsets and those offsets are registered, all stakeholders receive assurance that the offsets represent real atmospheric benefits. After quantifying the offsets generated from a project, developers must make public a written report addressing key aspects of the project such as responsible parties, land-management activities, and tons of offsets the project generated. This report ensures transparency and makes verification possible. Verifiers act as auditors of the offset process, and offsets must be independently verified before a developer can market them. Verifiers refer to documented plans to confirm that the methods, data, and calculations used to quantify net GHG benefits are reliable. To avoid conflicts of interest, verifiers should not be involved in the project in any other capacity. Project developers typically divide a project into accounting periods during which they quantify and market offsets. Accounting practices need to be specified to establish a single point where GHG benefit is counted in order to avoid double counting. Registering offsets with an appropriate agency assigns the owner a unique identifier and all subsequent transfers are amended within the registration, making the ownership of offsets unequivocal. Historical record ensures integrity and allows for audits by third parties or a regulating agency.

Aggregating offsets. Buyers may prefer to purchase aggregates of offsets instead of contracting with many landowners and project developers. This provides a role for retailers and brokers, who can aggregate offsets from numerous landowners, ensure that the offsets are reliably measured and verified, and provide blocks of "clean" offsets to the market. Retailers and brokers do not own offsets, but buyers may prefer to work with them because as an entity, they are in a better position to make up any shortfalls in the offsets they agree to provide buyers with. Perhaps, as well, there is a role for insurance companies to provide compensation to the insured if a project does not produce the anticipated offsets. And, because offsets are property, participants need a contract before the project begins that clearly articulates the nature of the project and allocates costs, risks, liabilities, and profits. For example, a contract may specify delivery of a fixed number of tons, or they may require (or prohibit) specified activities and transfer all resulting tons to the buyer. These contracts can involve a perpetual commitment to keep carbon stored, or they may run for a fixed period. A buyer can secure a perpetual obligation by obtaining a property interest from the seller, for example in the form of an easement.

Critical Lands/Water Identification Project (CLIP)

A comprehensive inventory of Florida's lands and waters is essential to provision the development of appropriate land use planning in the face of climate change. This report shows that land use is itself a regional climate-forcing agent. Thus, effective efforts at mitigation require that policy makers consider the entire range of competing uses and their potential consequences. The first phase of such an inventory has been completed under the auspices of the Century Commission (Oetting and Hoctor 2007). CLIP Phase I is the first step in a process to develop a statewide, decision support database for identifying important opportunities to protect Florida's essential ecosystems. CLIP combines a wealth of GIS (Geographical Information System) data from several sources to provide the most comprehensive database yet assembled for Florida. The available data were assembled and assessed with the help of a diverse team of advisors, and criteria were developed for identifying levels of criticality for biological and water resources (criteria described in Oetting and Hoctor 2007). Potential land use conflicts by 2020 and 2060 with critical biological and water resources are shown in Figure 18 (based on Zwick and Carr 2006). It is clear from this analysis that decisions made over the next decade will have long-term consequences for the fate of Florida's natural resources.

One important use of these data is to determine the extent to which land use scenarios for climate mitigation can also conserve ecosystems and ecosystem services. While carbon markets can help conserve natural and managed ecosystems, they do not guarantee that all important ecosystem services will be supported or appropriately valued. Thus, CLIP provides an essential framework and set of constraints for developing a Florida state climate action plan. The next step in this process is to construct landscape carbon budgets for the state, with careful attention to the biological and water assets identified in CLIP Phase I. These budgets can then be used to provision the planning process for development of mitigation scenarios and participation in carbon markets.

CLIP is also critical information for effective adaptation to climate change. For the first time, we have a comprehensive assessment of the geographic distribution of critical biological and water resources. Proactive adaptive planning for climate change should include quantitative assessments of possible impacts on these resources as determined by regional climate models. For example, we can say with certainty that plans should be developed for ecological restoration of mangrove and salt marsh ecosystems as rising seas affect their distribution and abundance. Because managed systems fare better than natural systems, those resources that are not under active management should be assessed for viability in the face of climate change, and management plans should be developed where appropriate. Similarly, existing management plans should be modified to include best practices with respect to modeled projections of climate change. Better regional models would decrease the uncertainty involved in developing management scenarios.

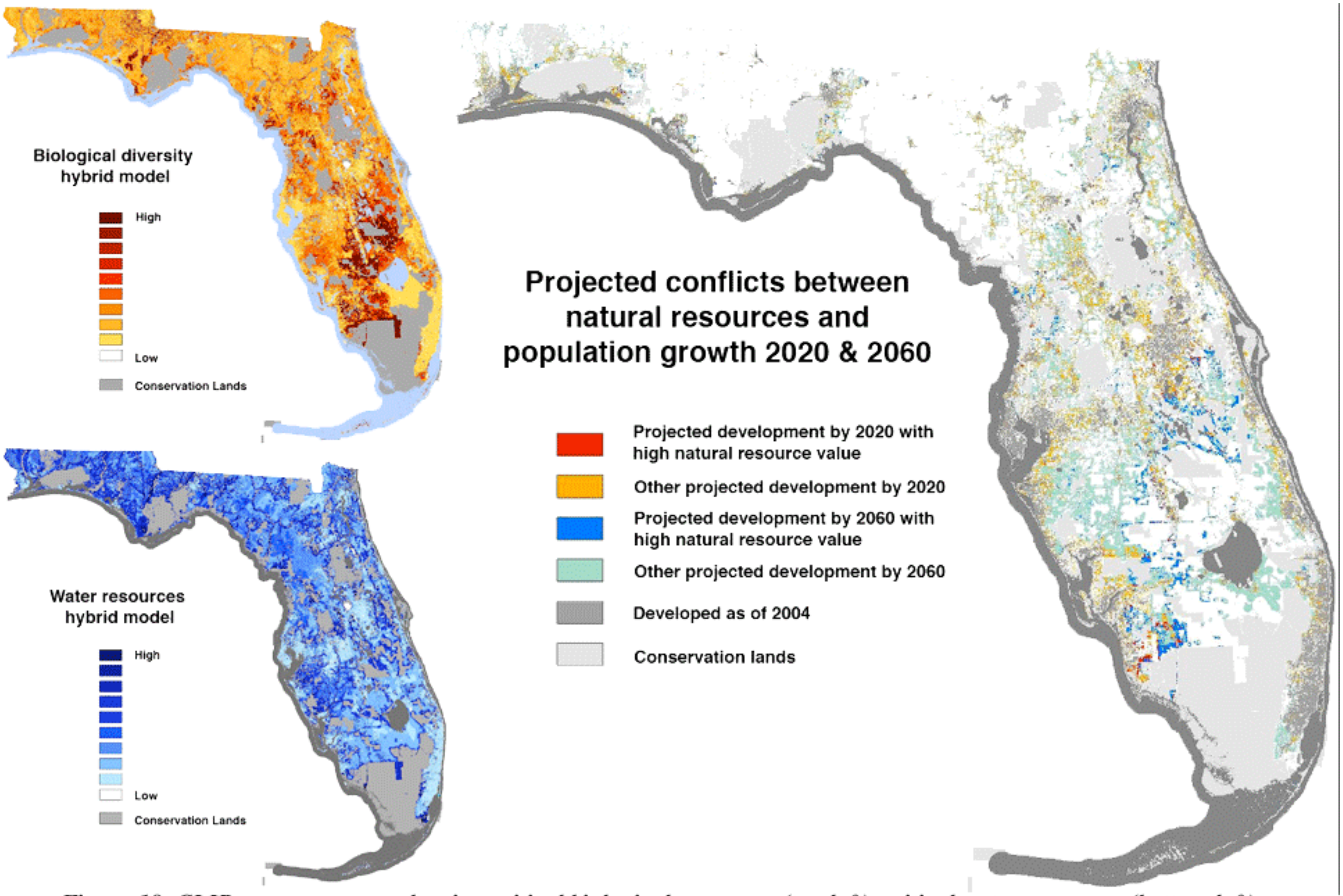


Figure 18. CLIP summary maps showing critical biological resources (top left), critical water resources (bottom left), and projected conflicts with growth by 2020 and 2060 (right); Oetting and Hoctor 2007.

Climate change and land use in Florida - Summary and options for action

This report shows that land use and climate change in Florida are deterministically linked issues. Changes in land use over the next decade can adversely affect climate change, while climate change itself will alter the form and function of the landscape. With its burgeoning growth, Florida stands at a crossroads with respect to its options for climate mitigation and adaptation. Failure to develop and implement appropriate plans for proactive adaptation could cost billions in lost revenue, while endangering the health and wellbeing of our children, grandchildren and beyond. Alternatively, tremendous opportunity exists for economic development through land management for climate mitigation and participation in carbon markets. While all adverse effects of global warming cannot be avoided through mitigation, proactive adaptation can confer resilience to managed and natural ecosystems, while creating jobs and opportunities for enhancing the wellbeing of Floridians.

Global warming effects on Florida

- Florida's climate will be adversely affected during this century by GHG forcing of the global atmosphere, but the speed and character of climate change are difficult to predict with existing models. Impacts will affect virtually every human and natural system in the state over the 21st century and beyond. Florida can develop a portfolio of adaptive strategies for addressing these impacts, while aggressively developing the capacity for GHG mitigation. A thorough GHG inventory including biological sources and sinks is an essential first step.

- If it chooses to participate in efforts to mitigate climate change, Florida can reduce its GHG emissions by shifting to renewable, non-fossil sources of energy, and improving efficiency of energy production and use across the sectors of power generation, transportation, and the built environment.

- A reasonable projection is that sea level will rise in a nonlinear fashion by 3 ft and possibly more by 2100. Florida could develop a plan for strategic retreat from the coast, and develop proactive adaptive scenarios for preserving critically threatened coastal habitat and human infrastructure. CLIP is an important tool for this exercise.

- The influence of anthropogenic climate change on Atlantic hurricane frequency and intensity is unresolved in the scientific literature. Because rising sea surface temperatures may be a primary driver of intense hurricanes, it is risky to assume that major hurricanes will be rare over this century.

Land use effects on regional climate

- The most significant negative short-term effect on mesoscale climate will be from urbanization and vegetation cover change associated with sprawl and land use change. Efforts at climate mitigation that are most likely to have near-term positive effects should be directed toward managing the state's growth and land use so as to stabilize mesoscale changes in climate.

- It is important that Florida develop regional climate models capable of modeling heterogeneous atmospheric forcing within the three climate zones of Florida. Targeted major funding for climate research groups at the state universities and collaboration of state agencies with national and international climate modeling groups would help move this effort forward. The results of these models can be integrated into the state's economic projections.

- Because of Florida's rapid human population growth, there is likely less than a decade remaining to avoid significant additional mesoscale climate change. It is possible to develop and implement best-practices to mitigate climate change resulting from changes in land use.

Lands associated with agriculture, forestry, and natural ecosystems

- Florida can become a leader in mitigation of GHGs through effective management of agriculture, forestry, and natural ecosystems. Mitigation in these sectors can significantly offset the projected increase in fossil-derived GHGs over this century. Such management will not be possible without comprehensive data on the carbon budgets and emissions of these systems. The state could develop the resources necessary to collect these data.

- Florida soils have the highest soil organic carbon content of all the states, and through proper management can sequester significant quantities of additional carbon. Agricultural lands can be managed to reduce CH_4 and N_2O through conservation tillage and management of livestock wastes. Biofuel crops and biogas production can significantly reduce the use of fossil fuels.

- Afforestation and management of industrial forests for both fuel wood and carbon sequestration provide the largest single land-use opportunity in Florida for climate mitigation over this century. To prepare for participation in carbon markets, the state could immediately begin to assess its forestlands and develop best-practices for management. Because much of Florida's forests are under private ownership, the legislature could consider mandates and incentives for the management of carbon on these lands.

- There is no comprehensive assessment of the carbon dynamics of Florida wetlands, and because of their significant carbon stores and CH_4 emissions it is important that these data be developed. Loss of carbon from the vast stores in the Everglades can be reduced through proper management of hydroperiod and control of wildfires. Current wetland mitigation and wetland banking practices can be reviewed in the context of climate mitigation.

Land management for participation in carbon markets

- Development of carbon markets is an unparalleled opportunity for monetizing ecosystem services and thereby progressively incorporating the natural economy into the human economy. Through targeted land use, Florida can participate in carbon markets with the potential for development of a major new source of revenue.

- For carbon markets to function effectively there must be transparent and comprehensive accounting of carbon sequestration, reversal, and leakage associated with biological systems over spatial and temporal scales consistent with the goals of GHG mitigation. Existing state agencies can establish appropriate accounting and best-practices procedures, and provide a mechanism for certification of verifiers.

- Appropriate environmental safeguards are essential to insure that the methods of mitigation are consistent with the long-term health of Florida's ecosystems. CLIP is a comprehensive inventory that provides essential data for this purpose.

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