Texas Statewide Assessment of Forest Ecosystem Services

A comprehensive analysis of regulating and cultural services provided by Texas' forests

October 2013

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Abbreviations

ac	acre
Af	acre-feet
C	carbon
CO_2e	equivalent carbon dioxide
FIA	Forest Inventory and Analysis
GDP	Gross Domestic Product
GSP	Gross State Product
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NWI	National Wetlands Inventory
REAP	Regional Ecological Assessment Protocol
t	metric ton (tonne or Mg)
tC	metric tons of carbon
TDS	total dissolved solids
TSS	total suspended solids
USD	United States dollars
USDA	United States Department of Agriculture
WRR	water resources region
WTP	willingness to pay
yr	year

Forest Cover in Texas

The FIA definition of forest land - *Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and will be naturally or artificially regenerated.*

FIA-defined forest acres in Texas = 62.4 million acres (25.2 million hectares)

FIA-defined forest acres in urban areas = 581.4 thousand acres (235.3 thousand hectares)

FIA-defined forest acres in rural areas = 61.8 million acres (25.0 million hectares)

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Highlights

- Texas has 62.4 million acres of uniquely diverse, [1]*FIA-defined* forests.
  - 12.1 million acres are located in 43 East Texas counties.
  - 50.3 million acres are located in 211 Central/West Texas counties.
  - 581.4 thousand acres are located in urban areas of Texas.
- Texas forests provide numerous ecosystem services valued at $92.9 billion annually.
  - Watershed regulating = $13.2 billion/year
  - Climate regulating = $4.2 billion/year
  - Biodiversity services = $14.8 billion/year
  - Cultural services = $60.4 billion/year
  - Air quality services = $190.3 million/year
- Watershed regulating services were assessed as three primary functions:
  - Water capture = $489.7 million/year
  - Water filtration = $4.2 billion/year
  - Water regulation = $8.5 billion/year
- Climate regulating services were assessed through the forest's capacity to store and accumulate carbon.
  - Carbon storage = $3.1 billion/year
  - Carbon accumulation = $1.2 billion/year
- Biodiversity services were assessed through a base value provided by all forests as well as additional value for ecologically important areas (hotspots).
  - Biodiversity base = $14.5 billion/year
  - Biodiversity hotspot = $326.1 million/year
- Cultural services were assessed based on the aesthetic, educational, cultural heritage, and passive use benefits forests provide.
  - An average Texas household is willing to pay between $0.54 - $2.22/year for a 1,000-acre increase in forest area depending on the type of forest.
  - Rural forests = $59.2 billion/year,
    - ✓ Privately owned = $35.0 billion/year
    - ✓ Publicly owned = $3.0 billion/year
    - ✓ Non-East Texas Woodlands = $21.1 billion/year
  - Forests in Urban areas = $1.2 billion/year
- Rural forests totaled 61.8 million acres and provided ecosystem services valued at $90.6 billion annually.
- The 581.4 thousand acres of FIA-defined forest in urban areas of Texas provided ecosystem services valued $2.3 billion annually.

Value (million $/yr) of assessed ecosystem service of FIA-defined forest in rural and urban areas of Texas		
Service	Rural (61.8 million acres)	Urban (581.4 thousand acres)
Watershed	12,495.17	724.60
Climate	4,230.85	23.65
Biodiversity	14,672.04	136.47
Cultural	59,173.19	1,202.50
Air Quality	-	190.29
Total	**90,571.24**	**2,277.52**

[1]Forests are defined by the USDA Forest Service, Forest Inventory and Analysis Nation Program (FIA) as *Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and will be naturally or artificially regenerated.*

Executive Summary

Introduction

The value of traditional goods, such as timber, from Texas' forests has long been recognized to be of economic importance to society. This value is relatively easy to assign. However, there is far greater worth to Texas' abundant forests and woodlands than realized by the value of wood fiber, wildlife and recreation. Texas forests provide numerous ecosystem services that are essential to the survival and well-being of all citizens in Texas. Yet, because no markets exist in which to buy and sell these services, they are not appropriately valued. This assessment estimates the economic value (2011 USD) that forest-based ecosystem services provide to society. The scope of this effort covers all forests in Texas, as identified by the USDA Forest Service Forest Inventory and Analysis (FIA) Program, and focuses on the following ecosystem services:

1. climate regulation: the effect forests have on regional and local climates by absorbing greenhouse gases such as carbon dioxide, and then storing them long-term in forest biomass and long-lived forest products;
2. watershed regulation: the ability of forests to provide a continuous, stable supply of clean drinking water through hydrological processes including water capture (water supply), water filtration (water quality), and water regulation/disturbance prevention (flood control and storm protection);
3. biological diversity regulation: the capacity of forests to promote essential biological diversity that drive most other services, as well as provide a sustainable habitat for wild plants and animals, soil formation/conservation, and pollination;
4. cultural values: the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, and aesthetic experience.

Values are reported for the state, by region (*East Texas* – 43 counties, *Central/West Texas* – 211 counties), and for seven ecoregions (*Pine Woodlands, Coastal Woodlands, Post Oak, Hackberry – Oak, Mesquite – Juniper, High Plains,* and *Mountain*) as shown in Figure 1. The value of timber and currently marketable recreational activities (e.g. hunting, fishing, camping, and bird watching) is not reported in this document because the economic contribution of these goods and services is currently documented in other available reports.

Figure 1. Map of the Texas regions (A = East Texas, B = Central/West Texas) and ecoregions (1 = *Pine Woodlands*, 2 = *Coastal Woodlands*, 3 = *Post Oak*, 4 = *Hackberry - Oak*, 5 = *Mesquite - Juniper*, 6 = *High Plains*, 7 = *Mountain)* used in this assessment. Forest cover is shown in green.

Watershed Regulating Services

Forests play an integral role in maintaining a continuous, stable supply of clean drinking water for millions of people throughout the state. To assess the economic contribution forests provide, watershed services were categorized into three primary functions (water capture, water filtration, and water regulation/disturbance prevention) and assessed over six forest cover types (non-riparian forests, riparian forests, and wetland forests in both rural and urban settings). Watershed values, based on the forest cover type, were assigned to each primary function, applied to their representative area across the State as denoted by FIA data, and totaled for an overall watershed ecosystem service value.

The water capture function (water supply) was assessed based on the value of water for instream and offstream uses in each water resource region (WRR) in Texas. The amount of water originating annually on Texas forestlands was estimated to be 20.0 million acre-feet. After accounting for the impact of woody plant encroachment (-$71.5 million/year), the total water capture value was $489.7 million/year, the majority of which was derived from *East Texas* (74%), the *Pine Woodlands* ecoregion (63%), and rural non-riparian forests (67%) throughout the State.

The water filtration function (water quality) was assessed based on the ability of forests to purify water and reduce water treatment costs. The total value of this function was $4.2 billion/year, with rural wetland forests accounting for 68% of this value. *East Texas* represented 59% of the value. The *Pine Woodlands* ecoregion (47%) provided the highest water filtration value, while the *High Plains* ecoregion (0.5%) provided the lowest.

The water regulation/disturbance prevention function (flood control) was assessed based on the ability of forests to control the timing and delivery of streamflow, effectively managing stormwater runoff. The total value of this function was $8.5 billion/year, 65% of which came from *East Texas*. Rural wetland forests accounted for 82% of the total value.

The total Watershed Regulating Service value provided by Texas forests was $13.2 billion/year, with 64% of this value made up by the water regulation function, followed by water filtration (32%) and water capture (4%). Rural wetland forests accounted for 75% of the total value, followed by rural riparian forests (15%). *East Texas* and the *Pine Woodlands* ecoregion represented 64% and 51% of the total value, respectively.

Climate Regulating Services through Carbon Sequestration

The valuation of carbon as an ecosystem service in climate regulation is key to determining the total value forests provide society. Forest carbon was assessed by stocks (current reserve of carbon held by forest biomass) and accumulation (the rate at which carbon is removed from the atmosphere and fixed into forest plant biomass). Since carbon is highly dependent upon the species composition and makeup of the forest, nine broad forest types, grouped based on similarities in growth habits and site characteristics, were identified. FIA data were used to estimate carbon stocks by five project-specific carbon pools. A conservative value of $22 per metric ton of carbon (tC) was used as the value of carbon stocks and accumulation. The economic value of carbon stocks was amortized over 20 years to get an annualized carbon stock value.

The total carbon stock estimated for all Texas forests was 2.1 billion metric tons (*East Texas* = 38%; *Central/West Texas* = 62%) across 62.4 million forested acres. Total annual economic value of this stock was $3.1 billion/year (*East Texas* = $808.1 million; *Central/West Texas* = $2.3 billion). In the *East Texas* region, the *Pine* forest type contributed, by far, the greatest total annual value at $374.5 million, which is more than twice that of the next highest forest type. In the *Central/West Texas* region, *Mesquite* forest type stocks were 758.8 million tC, twice as large as the next largest forest type, and valued at $1.1 billion annually. Unlike the *East Texas* region, which had equal *live tree above ground* and *soil organic* carbon pools, all forest types in *Central/West Texas* region had up to 80% of the carbon stock in the *soil organic* pool and relatively little carbon in the *live tree above ground* pool. This suggests that management efforts that reduce, but not eliminate, tree cover on these acres could restore the more historic ecosystems without significantly impacting carbon stocks.

The total carbon accumulation rate by all above ground, live vegetation across Texas forests was 52.8 million tC/year (*East Texas* = 12.2 million tC/year; *Central/West Texas* = 40.6 million tC/year), providing an annual economic value of approximately $1.2 billion (*East Texas* = $269.2 million/year; *Central/West Texas* = $893.1 million/year). Together, the total economic value of carbon stocks and carbon accumulation potential of Texas forestland equaled $4.3 billion/year (*East Texas* = $1.1 billion/year; *Central/West Texas* = $3.2 billion/year). The annual economic value of carbon stock and carbon accumulation across the project-defined ecoregions was: *Pine Woodlands* = $899.5 million; *Coastal Woodlands* = $162.9 million; *Post Oak* = $463.1 million; *Hackberry-Oak* = $1,027.9 million; *Mesquite-Juniper* = $1,359.8 million; *High-Plains* = $150.1 million; and *Mountain* = $207.2 million.

The averaged, per acre estimates of total carbon stocks for all forests was 33.7 tC/acre (*East Texas* = 45.0 tC/acre; *Central/West Texas* = 30.9 tC/acre). The amortized, average annual economic value of current carbon stocks was $49.8/acre/year (*East Texas* = $66.6/acre/year; *Central/West Texas* = $45.7/acre/year). The annual economic value of carbon accumulation averaged across all forest types and weighted by total acres per forest type was $18.6/acre/year (*East Texas* = $22.2/acre/year; *Central/West Texas* = $17.8/acre/year). Together, the total economic value of carbon stocks and carbon accumulation potential for all Texas forests averaged $68.4/acre/year (*East Texas* = $88.8/acre/year; *Central/West Texas* = $63.5/acre/year).

Biological Diversity Regulating Services

Biological diversity (biodiversity) is a source of value in forests. Biodiversity may be considered a valuable resource because it underpins all ecosystem functioning and concomitant ecosystem services (e.g., carbon sequestration, water filtration, etc.) that are essential in supporting human existence. To value biodiversity in Texas, a two-tier process was used. First, a base economic value was determined for each acre, representing the conservation cost of forgoing alternative land uses. A conservative value of 1% of Texas' Gross State Product was used as the base value to provide the necessary biodiversity needed for human well-being. Thus, each acre was valued at approximately $232.0 for its contribution towards biological systems, which is comparable to the value used by other ecosystem assessments in the southern U.S. The base economic value from biodiversity services, across all FIA-defined forests in Texas, was $14.5 billion/year. The forests in the 43 *East Texas* counties provided $2.8 billion/year, while the remaining counties in *Central/West* Texas contributed more than $11.7 billion/year.

Secondly, additional value was assigned to acres identified as "hotspots" of ecological importance using the Regional Ecological Assessment Protocol (REAP) provided by U. S. Environmental Protection Agency (EPA) Region 6. Based upon the Willingness to Pay (WTP) values reported in the literature, a conservative value of $51.75/acre/year was assigned to the top 10% of ecologically significant acres. Texas had 6.3 million acres that fell within this category (i.e., "hotspots") for the region, providing an additional annual ecosystem service value of $326.1 million/year. The *East Texas* region had 974.8 thousand "hotspot" acres valued at $50.4 million/year. The *Central/West Texas* region had 5.4 million "hotspot" acres valued at $275.6 million/year. Stacking the base biodiversity value and ecologically important value together, biodiversity services on FIA-defined forests provided a total annual economic value to Texas of $14.8 billion/year ($237.2/acre/year). The *East Texas* region and *Central/West Texas* region were valued at $2.9 and $11.9 billion annually, respectively.

Cultural Services

People enjoy the opportunities that Texas' forests provide towards spiritual enrichment, mental development, and leisure. Texas forests are a critical source for science, culture, art and education. These non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, and aesthetic experience are called cultural services which are the focus of this section.

To capture the cultural values associated with Texas forests, a survey was distributed to randomly selected Texas residents to determine their preferences and opinions about Texas forests. Survey results, using the stated choice modeling approach, were used to estimate the economic values attached to these cultural services. A total of 683 questionnaires were collected including mail and web-based surveys. The results for respondents' perceptions and experiences with forest ecosystems services were:

- 75% of respondents indicated they have at least some level of understanding of forest ecosystem services.
- 91% indicated that they intend to visit Texas forests in the future.
- 50% of respondents acknowledged that forests provide environmental benefits (air, water, carbon storage, wildlife habitats, and scenic view).
- 70% thought public rural forests should be primarily managed to provide recreational opportunities.
- 68% thought private rural forests should be primarily managed to provide fiber and other forest products.
- 60% of the respondents strongly agreed or agreed that forest landowners should be compensated for economic loss due to harvest restrictions for environmental benefits.
- 43% of the general public trusted forest owners in Texas to maintain healthy forests.
- 91% of the respondents strongly agreed or agreed that improved forest health and resilience benefits all citizens.

Data from the stated choice questions were analyzed using a logistic regression model to estimate the annual willingness to pay. An average household in Texas was willing to pay between $0.54 - $2.22/year for a 1,000-acre increase in forest area, depending on the type of forest. The estimated cultural values for rural forests and woodlands ranged from $140 – $3,275/acre/year depending upon region, forest type and ownership. Publicly owned rural forestlands in the *Post Oak* region ranked the highest at $3,275/acre/year. The estimated cultural values for urban forests ranged from $480 – $4,300/acre/year, with public urban forestland in the *Post Oak* region ranking the highest. The total cultural value of Texas forests to the residents of Texas is approximately $60.4 billion/year, including $59.2 billion/year for 61.8 million acres of rural forests and $1.2 billion/year for 581.4 thousand acres of forests in urban areas of the State.

Value for Texas

The annual contribution of the assessed cultural and regulating ecosystem services to the citizens of Texas is an estimated $92.9 billion each year across all forested acres. Rural forests were valued at more than $90.6 billion annually (Table 1). If represented on a per acre basis, Texas' rural forests provide $1,464.54 worth of ecosystem services annually. The *East Texas* region contributed 27.5% ($25.4 billion/year) and the *Central/West Texas* region provided 72.5% ($66.9 billion/year).

Forests in urban areas were valued at approximately $2.3 billion annually (Table 2). If represented on a per acre basis, Texas' urban forests provide $3,106.25 worth of ecosystem services annually. Urban forests in the *East Texas* region contributed 35.3% ($755.2 million/year) and the *Central/West Texas* region provided 64.7% ($1.4 billion/year).

Table 1. Ecosystem service value of FIA-defined forests within rural areas by region. Values may reflect slight discrepancies due to rounding.

Ecosystem Service	Unit Value ($/ac/yr)	Value (million $/yr)
Watershed		
Texas	202.05	12,495.17
East Texas	683.44	8,096.27
Central/West Texas	136.79	6,839.23
Carbon		
Texas	68.41	4,230.85
East Texas	89.13	1,055.81
Central/West Texas	63.44	3,171.82
Biodiversity		
Texas	237.25	14,672.04
East Texas	236.23	2,798.46
Central/West Texas	237.49	11,873.58
Cultural		
Texas	956.83	59,173.19
East Texas	1,137.20	13,471.73
Central/West Texas	899.81	44,987.14
Totals		
Texas	**1,464.54**	**90,571.24**
East Texas	**2,146.00**	**25,422.27**
Central/West Texas	**1,337.53**	**66,871.78**

Table 2. Ecosystem service value of FIA-defined forests in urban areas by region.

Ecosystem Service	Value ($/ac/yr)	Value (million $/yr)
Watershed		
Texas	1,246.25	724.60
East Texas	1,553.34	353.32
Central/West Texas	1,170.30	414.25
Carbon		
Texas	41.85	23.65
East Texas	48.59	11.05
Central/West Texas	35.59	12.60
Biodiversity		
Texas	234.72	136.47
East Texas	233.51	53.11
Central/West Texas	235.50	83.36
Cultural		
Texas	2,068.18	1,202.50
East Texas	1,477.24	336.01
Central/West Texas	2,447.91	866.49
Air Quality		
Texas	327.28	190.29
East Texas	195.10	74.44
Central/West Texas	136.42	115.85
Totals		
Texas	**3,918.27**	**2,277.52**
East Texas	**3,639.96**	**827.94**
Central/West Texas	**4,216.58**	**1,492.54**

Introduction

From the Pineywoods of East Texas to the inland waterways, wetlands and extensive coastline to the high mountain forests of the west, Texas is famous for its vast area and rich diversity. Texas has more than 62.4 million acres of forests, rich in diversity and located throughout the State. The annual contribution of forest-based manufacturing and forest-related recreation and tourism to the Texas economy in 2009 was over $23 billion. This value is traditional and relatively easy to assign. However, Texas forests provide numerous ecosystem services worth far more than the value of wood fiber and recreational activities such as hunting, fishing, and camping. Ecosystem services are essential to the survival and well-being of all citizens in Texas, yet they are often taken for granted.

For these reasons, Texas A&M Forest Service, set out to quantify the services provided by forests and woodlands in Texas, and to estimate the associated value of these benefits. Recognizing these values is paramount to smart land use planning and the long-term sustainability of Texas forests. If the usual cost-benefit analysis can be expanded to incorporate the economic impact of a variety of forest ecosystem services provided to society, then a more realistic and clearer assessment of the full costs and benefits of both the landscape itself, as well as landscape changes, can be realized. All values used in this report, unless otherwise noted, are expressed in year 2011 United States dollars (USD).

Defining Ecosystem Services

The value of traditional goods such as timber, wildlife and recreation has long been recognized to have an economic value. Forested ecosystems also provide a wide array of services that benefit society. These services can be placed within three broad categories (Table 3): 1) provisioning, 2) regulating, and 3) cultural (Millennium Ecosystem Assessment [MEA] 2005). Provisioning services are the material goods provided by nature that already have an economic value. Some of these, such as food (e.g., crops, livestock, and fisheries) and fiber (e.g., timber, cotton, wood fuel) are familiar to Texans. Other less familiar services include genetic resources, biochemical advances, fresh water, natural medicines, pharmaceuticals, and ornamental resources. Regulating and supporting services, from an anthropogenic point of view, control environmental processes that are essential to the survival of humans. Because of their complexity and grand scale, regulating services cannot effectively be replaced by current technology. Lastly, cultural services are the non-material, emotional benefits people obtain from ecosystems through aesthetic values, social relations, reflection, recreation, spiritual enrichment and cognitive development (Millennium Ecosystem Assessment [MEA] 2005).

The project's scope was all forestland in Texas, including both private and public ownership, as defined by FIA. Based on a literature review, the balance transfer approach was used to estimate the value (2011 USD/acre) for some generally accepted ecosystem services. Through original research, a non-market valuation approach (stated choice) was used to estimate per acre cultural values of forests.

Why Texas Forests and Why Now?

The State has a wealth of diversity within its forest resources. Texas forests are critical renewable natural resources, providing services that millions of people rely upon; however, urbanization is permanently converting these areas to other, non-natural land uses. As Texas becomes more urbanized and people move near forests, an ever-increasing demand for resources will impact the ability of the natural ecosystem to provide services that are essential to life and well-being. At this time, even if individuals are aware of the services provided, landowners are neither compensated for providing these services nor penalized for reducing them. Ecosystem services are not products or commodities in the strict sense, so they do not drive policy or appear on Texas' economic balance sheet. So the question remains, "How much are these natural benefits worth to society?" The non-marketed benefits are often high and more valuable than the marketed benefits. Placing a value on these services and educating policy makers about these values may help put incentives in place to encourage management of forestlands. This, in turn, will have additional benefits to the quantity of services provided by these lands, minimize the potential for catastrophic loss from fire, insect, disease, and extreme weather events that have huge social costs, and reduce forestland conversion and fragmentation during land-use planning. To address these needs, the project's goals were to:

1. identify key forest-based ecosystem services of high importance to both private landowners and the general public;
2. quantify the ability of forests to provide key ecosystem services annually using existing data;
3. estimate the conservative economic value of critical regulating and cultural services;
4. use this information to report changes in values following natural disasters, land conversion, and the implementation of conservation programs; and
5. develop a framework so values can be updated periodically as new data becomes available.

Table 3. Description of regulating and cultural services evaluated in this assessment.

Air and Climate Regulation	
Climate regulation	The influence forests have on the regional and local climate by either emitting or absorbing greenhouses gases and/or aerosol. Example: carbon sequestration.
Air quality regulation	The influence forests have on improving air quality by trapping soot (particulate matter), nitrogen oxides, and other pollutants.
Watershed Regulation	
Water capture	Infiltration, percolation, and aquifer recharge.
Water filtration	Filtration and decomposition of organic waste. Assimilation and detoxification.
Water regulation	Timing and magnitude of runoff and flooding.
Biological Diversity Regulation	
Biodiversity	Storehouse of genetic material, contribution to natural pest and disease control, pharmaceutical products, pollination of essential plants, threatened and endangered species.
Cultural Services	
Cultural	Non-material, emotional benefits people obtain from ecosystems through aesthetic values, social relations, reflection, recreation, spiritual enrichment and cognitive development.

This report includes the following chapters:

- *Value of Forest Watershed Services*: This chapter uses the spatial distribution of water supply and forest cover types to estimate the total and per acre economic value of hydrologic services for all forests in the State, regions, and ecoregions.
- *Value of Forest Carbon Services:* This chapter estimates the current carbon stocks held by Texas forests, applies the annual carbon accumulation rate for specific forest types, and estimates the total and per acre economic value of this service for all forests in the State, regions and ecoregions.
- *Value of Forest Biodiversity Services:* This chapter presents an economic analysis of the value of conserving biologically diverse forest ecosystems and protecting ecologically important forest areas.
- *Value of Forest Cultural Services*: This chapter estimates the cultural values of Texas forests through an original, online and mail version, stated-choice survey of Texans.

- *Summation of Forest Services in Texas*: This chapter summarizes the value of the assessed cultural and regulating ecosystem services provided by all forests in Texas.

Table 4. List of ecosystems services assessed on FIA-defined forests in this report by rural and urban areas.

	Forestland (62.4 million acres)	
Ecosystem Service	Rural	Urban
Watershed		
Water Capture	✔	✔
Water Filtration	✔	✔
Water Regulation	✔	✔
Climate		
Air Quality		✔
Carbon Accumulation	✔	✔
Carbon Stocks	✔	✔
Biodiversity		
Base	✔	✔
Hot Spot	✔	✔
Cultural		
Cultural	✔	✔

Determining Forested Acres / Spatial Representation

FIA data (2010) was used to estimate the number of forested acres in Texas. This program continuously measures a series of permanently-established plots to provide objective and scientifically credible information on growth, composition, mortality, ownership, disturbance, and many other variables for forests and woodlands in the State. FIA data represent a comprehensive, unbiased, and consistent sample dataset of known accuracy that has long been used for mapping (Blackard et al., 2008; Riemann Hershey, 2000; Zhu and Evans, 1994). Since this data is updated regularly, future map updates are possible. In Texas, 10 - 20% of the plots within the State are re-measured each year through a cooperative agreement between the Texas A&M Forest Service and the Southern Research Station of the USDA Forest Service. Results are reported for 43 *East Texas* counties and 211 *Central/West Texas* counties (Figure 2).

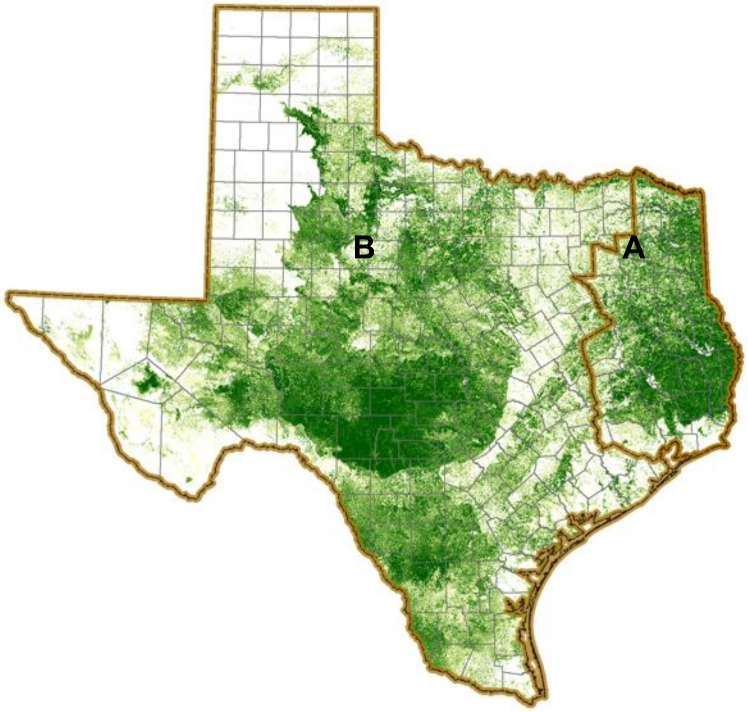


Figure 2. Delineation of the (A) *East Texas* and (B) *Central/West Texas* regions. Forest cover is shown in green.

Ecosystem services were also assessed by project-defined ecoregions corresponding to the ecological sections as mapped by the USDA Forest Service's National Hierarchical Framework of Ecological Units (Table 5). Sections are delineated primarily by evaluation and integration of physical and biological components including climate, physiography, lithology, soils, and potential natural communities (McNab et. al, 2007). The resulting project ecoregions illustrated in Figure 3 are a bit broader than the sections adopted by USDA Forest Service, but are more relevant to the analysis of this project.

Table 5. Name and description of each project-defined ecoregion used for this assessment as identified by a combination of one or more USDA Forest Service Ecological Sections.

Ecoregion	Description
Pine Woodlands	Aggregate of Mid Coastal Plains-Western, Coastal Plains and Flatwoods–Western Gulf
Coastal Woodlands	Aggregate of Louisiana Coastal Prairies and Marshes, Central Gulf Prairies and Marshes
Post Oak	Aggregate of Oak Woods and Prairies, Blackland Prairies
Hackberry–Oak	Aggregate of Texas Cross Timbers and Prairies, Cross Timbers and Prairies, Eastern Rolling Plains, South Central and Red Bed Plains, Rolling Plains
Mesquite–Juniper	Aggregate of Edwards Plateau, Rio Grande Plains, Stockton Plateau
High Plains	Aggregate of Northern Texas High Plains, Southern High Plains, Texas High Plains
Mountain	Aggregate of Basin and Range, Pecos Valley, Sacramento-Monzano Mountains

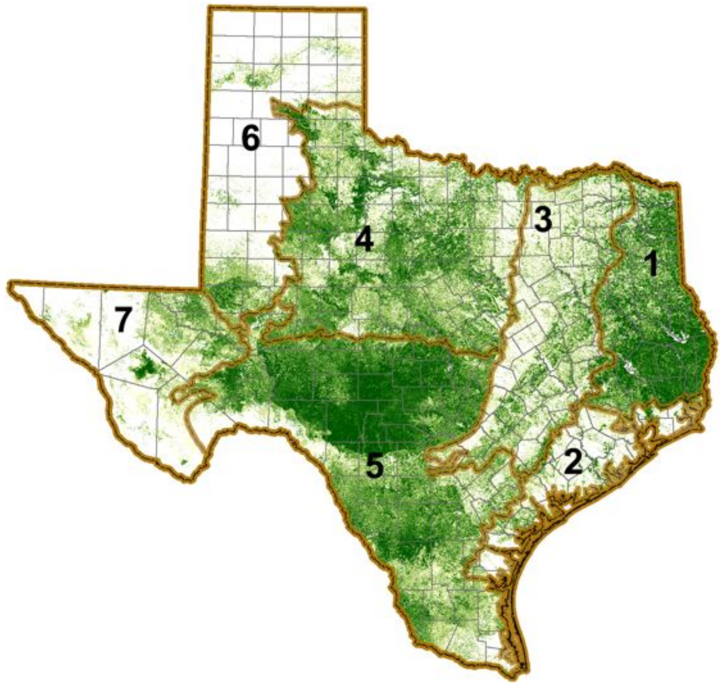


Figure 3. Resulting project-defined ecoregions from the combination of one or more USDA Forest Service Ecological Sections and corresponding forest cover as estimated from FIA data. Ecoregions include: 1) *Pine Woodlands*, 2) *Coastal Woodlands*, 3) *Post Oak*, 4) *Hackberry-Oak*, 5) *Mesquite-Juniper*, 6) *High Plains*, 7) *Mountain*.

Forestland

The FIA forestland geospatial layer shown in Figure 1, a 250-meter resolution raster derived from MODIS imagery, plot data, and soils information, was used extensively throughout this assessment. Forest area was calculated for the State, two broad regions, and seven project-specific ecoregions from this layer (Figure 2). In addition, NLCD was used in conjunction with this layer to estimate forests in urban areas. For a detailed discussion on this layer, see Appendix A.

A forest's ability to provide various ecosystem services is not only dependent upon the geographical location of the forest within Texas, but is also highly dependent upon the species composition and makeup of the forest. For this reason, nine broad forest types (Table 6) were identified for valuing the climate regulating service by combining available FIA forest type data with similar growth habits and site characteristics.

Table 6. Resulting project-defined forest types from the combination of one or more FIA Forest Type Groups.

Forest type	FIA Forest Type Group
Pine	Loblolly/shortleaf, Longleaf/slash
Hardwood-Pine	Oak/pine
Hardwood-Upland	Oak/hickory
Hardwood-Bottomland	Oak/gum/cypress
Hardwood-Riparian	Elm/ash/cottonwood
Hardwood-Other	Exotic hardwoods, Other hardwood group
Hardwood-Woodlands	Woodland hardwoods
Juniper	Pinyon/juniper
Other	Other eastern softwoods, nonstocked

Forests and the Texas Economy

Texas' forests provide more than just timber and other traditional, marketable products. The forests of Texas provide a suite of ecosystem services that are consumed by citizens every day. However, fair market value is not yet paid to the forest owner for these services. As a result, not all landowners are motivated to maintain and/or actively manage their forestlands to provide these ecosystem services. If fair market value existed, forest production and conservation would likely increase because forests would be more economically competitive with non-forest land use options, many of which are driving urbanization. In other words, if the total economic value of forestland is considered, and receives a real market value, then perhaps greater motivation would exist to keep forests in forests.

Forest and land use policy has not addressed this in large part because ecosystem services are difficult to quantify. Yet, society can ill-afford to lose these services provided by forests. As the science improves and more transactions occur in the emerging environmental marketplace, economic values people derive from nature will become better understood and better incorporated into the economy.

Value of Forest Watershed Services

Introduction

Over one-half of the nation's freshwater resources originate from forests that cover about one-third of the United States. Healthy forests are critically important to protecting water resources and sustaining them in the future. In fact, one of the primary reasons for establishing the National Forests was to protect the country's water resources (Organic Act, 1897). Forests provide a number of essential economic, social, and environmental functions in addition to supplying the cleanest water of any land use (Jackson et al., 2004; Sun et al., 2004). Forests absorb rainfall, refill groundwater aquifers, slow and filter stormwater runoff, reduce floods, and maintain watershed stability and resilience. The National Association of State Foresters clearly recognizes the connection between forests and water resources, stating in a 2005 position statement that "water, in all its uses and permutations, is by far the most valuable commodity that comes from the forest land that we manage, assist others to manage, and/or regulate." This chapter estimates the economic values of watershed services provided by Texas forests, including water capture, water filtration, and water regulation/disturbance prevention.

Methods

Forest watershed services were categorized into three primary functions (water capture, water filtration, and water regulation/disturbance prevention) and assessed over six forest land cover types (non-riparian forests, riparian forests, and wetland forests in both rural and urban settings). Watershed values based on the forest land cover type were assigned to each primary function, applied to their representative area across the State, and totaled for an overall watershed ecosystem service value. Values were also reported by region and ecoregion. While all of these primary functions are inter-related and inter-dependent, they were separated based on their fundamental service for valuation purposes. For example, forest soils typically have high organic matter, porosity, and permeability, resulting in high infiltration rates, and leading to additional water capture and storage capacity (Barten, 2006). These same characteristics, along with canopy interception, facilitate water regulation, which in turn, reduces flooding potential.

Primary Functions

Water Capture

Forests are very effective at capturing, storing, and steadily releasing water over time. Tree canopies intercept and absorb the kinetic energy of rainfall. Forest soils function like a sponge, absorbing large amounts of water through a process called infiltration. As a result, the amount of surface runoff from forested watersheds is relatively low. Water that is absorbed into the soil either percolates into underground aquifers, or is slowly released over time into nearby creeks, streams, and rivers. The cumulative effect of this function results in much more stable and consistent flows from forested watersheds, increasing the amount of available water. While developed watersheds may have higher short term peak flows, forested watersheds may have a higher percent of water available for use (Nagy, 2011).

Lack of groundwater recharge can have a substantial impact on the hydrology of streams. Baseflows (flow contributed by groundwater throughout the year) can be reduced and become so low that formerly perennial streams become intermittent during periods of dry weather. Some researchers have found that for every one percent increase in impervious surface cover, baseflow is reduced by two percent (Calhoun, 2003).

The water capture function can be thought of in terms of water supply and as such, was assessed based on the value of water for instream and offstream uses. This was done by estimating the amount of water originating on Texas forestlands and the marginal value of streamflow for each water resources region (WRR) in the State (Figure 4B). A spatial distribution map of available water supply in Texas (Figure 4A), estimated from precipitation and evapotranspiration model results across a 5,000 square meter grid by Brown et al., (2008), was overlaid with the FIA forestland layer to calculate the amount of water originating on Texas forestlands. The resulting water supply, by forest land cover type, was multiplied by the respective WRR's marginal value of streamflow, taking into account instream (recreation), hydroelectric, and offstream (irrigation, municipal, industrial, mining) uses. In a review of over 2,000 water transactions, Brown et al., (2004) estimated the following marginal values of streamflow (acre-foot/year) by WRR in Texas: $63.45 in the Rio Grande WRR, $28.96 in the Texas-Gulf WRR, and $19.31 in the Arkansas White-Red WRR.

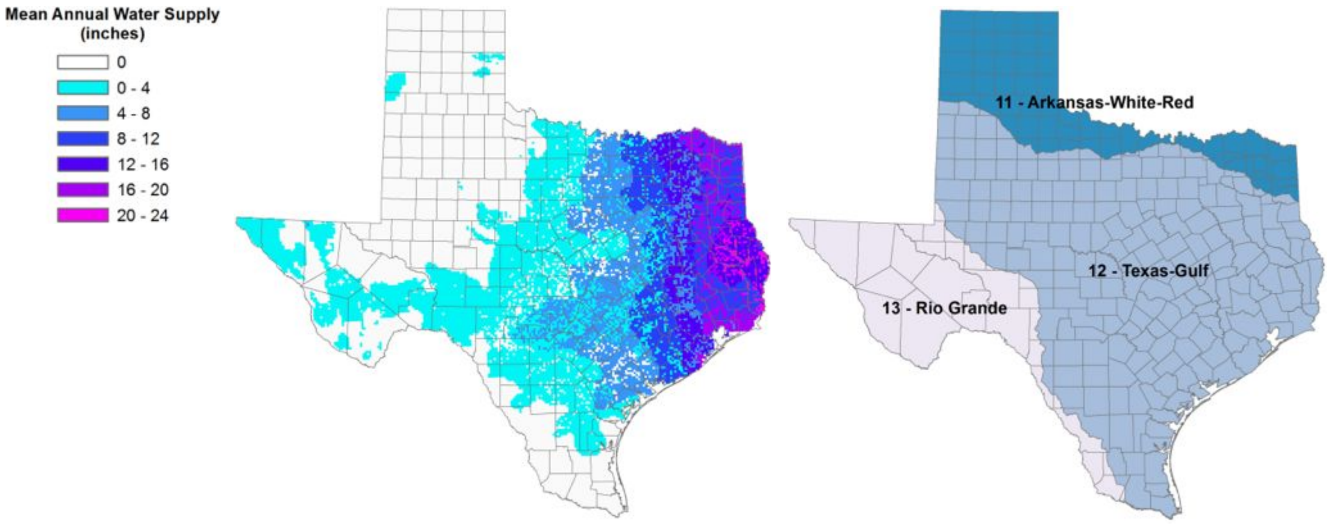


Figure 4. (A) Map of available water supply in Texas. (B) Map of Texas water resource regions.

While forest cover plays a critical role in water capture and storage, this function can be excessive in the semi-arid regions of the State. Woody species such as mesquite (*Prosopis* sp.), salt cedar (*Tamarix* sp.), and ashe-juniper (*Juniperus ashei*) encroaching upon the forests of *Central/West Texas* have the ability to intercept and transpire high amounts of precipitation. This ecological process can reduce the amount of water available for aquifer recharge and stream flow, negatively impacting the value of this primary function.

For several decades, land managers have cleared brush species such as mesquite and juniper (cedar) and observed increases in spring and streamflow (Jones, 2008). Numerous studies have been conducted over the years on the effects of brush control on rangeland hydrology. From this research, scientists have concluded that under certain conditions, brush control can substantially increase the amount of water reaching streams and aquifers. Under other conditions, brush control can have little or no effect (Bosch and Hewlett, 1982; Hibbert, 1983; Huxman et al., 2005; Rainwater et al., 2008; Thurow, 1990; Thurow et al., 2000; Wilcox, 2002; Wilcox et al., 2006). Wilcox et al., (2006) concluded that brush control is most likely to increase water yield in three key areas: 1) riparian areas with accessible groundwater and dominated by invasive riparian species such as salt cedar, 2) upland landscapes with woody species such as juniper and oak on soils that allow rapid deep drainage such as shallow or highly permeable soils over fragmented karst limestone like those in the Edwards Plateau, 3) mesquite growing on deep sandy soils like those in the Carrizo-Wilcox Aquifer recharge zone and heavy clay soils in the Blackland Prairie with high shrink-swell potential that can facilitate deep drainage through extensive soil cracks formed during dry periods.

To account for the impact on water capture of woody plant encroachment in these three key areas, total water loss was calculated by multiplying the respective forestland area within these zones by the average measured water yield (acre-feet/year) from brush control research projects (Table 7). Total water loss was valued using the respective WRR marginal streamflow rate and subtracted from the overall function valuation.

Table 7. Predicted increase in water yield (acre-feet/year) from brush control projects that reduce encroaching woody plant cover (Jones, 2008; TSSWCB, 2011).

Landscape	Species	Water Yield (Af/ac/yr)
Riparian Areas	Salt cedar	4.00
Edwards Plateau	Juniper/Oak	0.16
Carrizo-Wilcox	Mesquite	0.06
Blackland Prairie	Mesquite	0.10

Water Filtration

Forests, especially those in riparian and wetland areas, function as "nature's kidneys," slowing down stormwater runoff long enough for sediment, nutrients, and other pollutants, including toxic elements and heavy metals, to be deposited or absorbed before reaching waterways. Bacteria and microorganisms in forest soils break down these pollutants, facilitating plant uptake. Research has shown that maintaining a forest buffer as small as forty feet wide along each side of a stream or river can reduce sediment delivery by 71 - 99 percent (Ward and Jackson, 2004).

Water filtration provided by forests can significantly lower water treatment costs. Monitoring has shown that in-stream total suspended solids (TSS), total dissolved solids (TDS), and turbidity increase as forest cover decreases. A study of 27 water suppliers conducted by the Trust for Public Land and the American Water Works Association in 2002 found that protecting forestlands within public drinking water supply watersheds can reduce capital, operational, and maintenance costs for drinking water treatment. Within a watershed, reducing forest cover from 60 percent to 30 percent can increase drinking water treatment costs by 97 percent (Postel, 2005). Forest wetlands can also reduce the cost to treat wastewater. One study found that wetlands were 85 percent less expensive than conventional wastewater systems for every 1,000 gallons treated (Hanson, 2011).

The water filtration function provided by forests was assessed based on capacity to protect water quality and ultimately reduce water treatment costs. According to the water supplier study mentioned above, for every 10 percentage point increase in forest cover in the source area, treatment and chemical costs *decreased by* approximately 20 percent, leveling off after reaching 60 percent forest cover (Ernst, 2004). The potential increase in water treatment costs ($19.4/acre-foot) resulting from a decline of forest cover from 30% to 10% of the watershed, as reported by Ernst (2004), was used to assess the water filtration function. This value was applied to the amount of water originating on rural and urban non-riparian forests. This approach was based on a geospatial analysis that estimated the average percent forest cover in public surface water supply watersheds in highly urbanized areas (9%) and across the state of Texas (35%).

Riparian and wetland forests were valued separately for this function, based on their increased ability to filter contaminants from runoff water. In this assessment, riparian forests were valued at $120.2/acre, based on estimates of pollutant reductions (nitrogen, phosphorous, and sediment) and their values related to water treatment (Holmes, 1988; Riparian Forest Buffer Panel Technical Team, 1996; Potomac Watershed Partnership; 2011). Woodward and Wiu, (2001) evaluated the results from 39 studies to assess the relative value of different wetland services. The water quality function, based on reduced costs for water purification, was valued at $724.8/acre.

Water Regulation / Disturbance Prevention

Forests, through their ability to intercept rainfall, slow moving water with physical barriers, and absorb large amounts of water in porous and permeable soils, are very effective at regulating stream flow and managing stormwater runoff. This function can reduce the frequency and intensity of property damaging floods. While this service is more pronounced in urban settings, it is a critical function across all forestland cover types. Forests in urban areas were assessed a base value calculated from the estimated replacement construction costs ($662.9/acre) associated with managing stormwater runoff in the absence of green infrastructure (Wilson, 2008). Additional values, obtained from Liu et al., (2010), were added to riparian ($116.4/acre) and wetland ($1,758.2/acre) forest cover types to account for disturbance prevention.

Forest Land Cover Types

Forest watershed services were assessed over six forest land cover types listed below. For a detailed discussion on each cover type, please see Appendix A.

1. *Rural non-riparian forests* – This cover type was calculated by subtracting forests in urban, riparian, and wetland areas from the total forestland area as estimated by the FIA geospatial forestland layer. Within this cover type, the area occupied by mesquite (Blackland Prairie, well drained soils in the Carrizo-Wilcox Aquifer recharge zone) and dense forest cover (Edwards Plateau) was delineated using FIA forest type data.
2. *Rural riparian forests* – This cover type was delineated using the National Hydrography Dataset (NHD) high-resolution flowline data. Stream orders one to four were buffered by 50 meters, whereas orders greater than four were buffered by 100 meters. The resulting *Riparian Areas* layer, after removing urban areas, was combined with the FIA geospatial forestland layer to identify rural riparian forests. Within this cover type, the area occupied by salt cedar was delineated based on the 2006 National Land Cover Dataset, a 1960s USGS study, and personal knowledge of its extent.
3. *Rural wetland forests* – This cover type was identified using Class 90 (Woody Wetlands) of the *2006 National Land Cover Dataset* (NLCD). Wetland forests in urban areas were removed from this layer.
4. *Urban non-riparian forests* – This cover type was identified using the FIA geospatial forestland layer, the 2006 NLCD, and the *U.S. Census Cartographic Boundary* files. Forests within the boundary of urbanized areas or urban clusters as defined by the Census were delineated as the *Forests in Urban Areas* layer. Riparian and wetland forests were removed from this resulting layer.
5. *Urban riparian forests* – This cover type was identified by combining the *Forests in Urban Areas* and the *Riparian Areas* layers. The overlapping forests were delineated and classified as urban riparian forests.
6. *Urban forest wetlands* – This cover type was identified using Class 90 (Woody Wetlands) of the 2006 NLCD and the *U.S. Census Cartographic Boundary* files. Forested wetlands within the boundary of urbanized areas or urban clusters as defined by the census were classified as *Urban Wetland Forests*.

Forest Watershed Service Values

Ecosystem service values were estimated for the three primary watershed functions across six forestland cover types (Table 8) using the benefit transfer approach. Total watershed values by cover type are presented as an approximation since some function values are derived from the geographically based marginal value of streamflow.

Table 8. Forest watershed service values by function and land cover type.

Land Cover	Function			[b]**Total** ($/ac)
	Water Capture ($/ac-ft)	[a]Water Filtration ($/ac)	Water Regulation / Disturbance Prevention ($/ac)	
Rural non-riparian forest	19.31 – WRR # 11 28.96 – WRR # 12 63.45 – WRR # 13	5.21	0.0	**11.83**
Rural riparian forests	19.31 – WRR # 11 28.96 – WRR # 12 63.45 – WRR # 13	120.17	116.45	**242.34**
Rural wetland forests	19.31 – WRR # 11 28.96 – WRR # 12 63.45– WRR # 13	724.80	1,758.18	**2,508.84**
Urban non-riparian forests	19.31 – WRR # 11 28.96 – WRR # 12 63.45 – WRR # 13	12.63	662.96	**693.48**
Urban riparian forests	19.31 – WRR # 11 28.96 – WRR # 12 63.45 – WRR # 13	120.17	662.96 + 116.45	**916.08**
Urban wetland forests	19.31 – WRR # 11 28.96 – WRR # 12 63.45 – WRR # 13	724.80	662.96 + 1,758.18	**3,170.94**

[a]Water filtration values for non-riparian forests were converted from an acre-foot basis to a per acre basis.
[b]Total values for each land cover type are on a state-wide basis.

Results

There are 62.4 million acres of forestland in Texas, 12.1 million of which are in *East Texas* and 50.3 million are located in *Central/West Texas*. Rural riparian forests account for approximately 8.0 million acres, while rural forest wetlands and wetland-like areas cover almost 4.0 million acres. There are 581.4 thousand acres of forests in urban areas. Table 9 shows the number of forested acres by land cover type and region of the State.

Water Capture

The geospatial layer provided by Brown et al., (2008) of the spatial distribution of water supply in Texas (Figure 5) indicated that there is approximately 43.5 million acre-feet of water in the State (Table 10). Since this was calculated from the difference between precipitation and evapotranspiration, it encompasses all surface and groundwater sources found within the land area of the State, excluding submerged lands in the Gulf of Mexico. Overlaying the FIA forestland layer shows that 46% (20.0 million acre-feet) of this water originates on forestlands, the majority of which (66%) is located in *East Texas*. The *Pine Woodlands* ecoregion accounts for 57% of the State's forest-water supply. Applying the respective WRR water rates to this water supply, and subtracting $71.5 million attributed to woody plant encroachment (Table 11 and 12), produces a total water capture function value of $489.7 million (Table 13).

Table 9. Forestland (millions of acres) by land cover type and region. Values may reflect slight discrepancies due to rounding.

Region	Rural Non-Riparian Forests	Rural Riparian Forests	Rural Wetland Forests	Urban Non-Riparian Forests	Urban Riparian Forests	Urban Forest Wetlands	**Total**
Texas	49.87	8.00	3.97	0.36	0.10	0.12	**62.42**
East	7.61	1.31	2.93	0.13	0.02	0.07	**12.07**
Central/West	42.25	6.70	1.04	0.23	0.08	0.05	**50.35**
Ecoregion							
Pine Woodlands	6.44	1.06	2.34	0.10	0.02	0.04	**9.98**
Coastal Woodlands	1.24	0.16	0.49	0.05	0.01	0.05	**2.00**
Post Oak	4.03	0.87	0.81	0.09	0.04	0.03	**5.86**
Hackberry-Oak	12.63	2.52	0.08	0.05	0.02	< 0.01	**15.29**
Mesquite-Juniper	20.64	3.05	0.24	0.08	0.02	< 0.01	**24.03**
High Plains	2.21	0.12	0.01	<0.01	< 0.01	< 0.01	**2.34**
Mountain	2.68	0.23	0.01	< 0.01	< 0.01	< 0.01	**2.92**

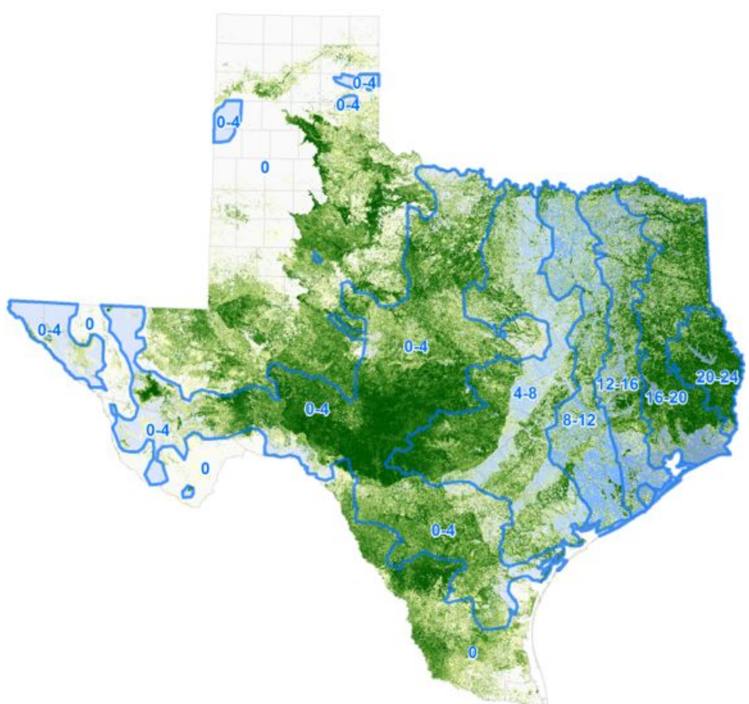


Figure 5. Map of available water supply (blue isolines) and forest cover (green).

Table 10. Available water supply (millions of acre-feet) in Texas by ecoregion. Values may reflect slight discrepancies due to rounding.

Region	Total Water Supply	Water Supply from Forest	Water Supply from Non Forest	% Water Supply from Forest	% Water Supply from Non Forest
Texas	43.48	20.04	23.44	46.09	53.91
East	23.04	13.31	9.73	57.77	42.23
Central/West	20.44	6.72	13.72	32.88	67.12
Ecoregion					
Pine Woodlands	16.76	11.35	5.41	67.72	32.28
Coastal Woodlands	6.29	1.21	5.08	19.24	80.76
Post Oak	12.84	3.74	9.10	29.13	70.87
Hackberry-Oak	3.70	1.48	2.22	40.00	60.00
Mesquite-Juniper	3.67	2.23	1.44	60.76	39.24
High Plains	0.03	< 0.01	0.03	2.32	97.68
Mountain	0.18	0.03	0.15	16.67	83.33

Woody plant encroachment in parts of *Central/West Texas* can contribute to losses in water capture as compared to native rangelands (Tables 11, 12, and 13; Figure 6). Salt cedar dominated riparian areas covered less than 2% of the acres associated with woody plant encroachment; however, they accounted for 31% of the total water loss and 29% of negative water capture value. The *Mesquite-Juniper* (72%), *Hackberry-Oak* (14%) and *Mountain* (11%) ecoregions accounted for 97% of all negative water capture values associated with woody plant encroachment.

Table 11. Area, water yield following brush control, total water loss, and negative water capture value of woody plant encroachment by landscape.

Landscape	Area (million acres)	Water Yield (ac-ft)	Total Water Loss (million ac-ft)	Value (million $)
Riparian Areas (Salt cedar)	0.15	4.00	0.60	-$20.92
Edwards Plateau (Juniper/Oak)	7.69	0.16	1.23	-$47.37
Carrizo-Wilcox (Mesquite)	1.41	0.06	0.08	-$2.82
Blackland Prairie (Mesquite)	0.12	0.10	0.01	-$0.36
Total	**9.38**	**0.20**	**1.93**	**-$71.47**

Table 12. Area, water loss, and negative water capture value of woody plant encroachment by ecoregion.

Ecoregion	Area (thousand acres)	Total Water Loss (thousand ac-ft)	Value (million $)
Pine Woodlands	< 0.01	< 0.01	< 0.01
Post Oak	186.85	16.71	-0.4
Hackberry-Oak	338.11	396.17	-9.91
Mesquite-Juniper	8,795.22	1,315.97	-51.74
High Plains	19.51	78.00	-1.60
Mountain	39.20	121.84	-7.73
Total	**9,378.89**	**1,928.69**	**-$71.47**

Table 13. Water capture function values (million $/year) by land cover type and region. Values may reflect slight discrepancies due to rounding.

Region	Rural Non-Riparian Forests	Rural Riparian Forests	Rural Wetland Forests	Urban Non-Riparian Forests	Urban Riparian Forests	Urban Forest Wetlands	**Total**
Texas	330.05	45.75	102.73	6.44	1.66	3.02	**489.66**
East	226.60	38.62	91.54	3.94	0.68	2.22	**363.61**
Central/West	103.45	7.14	11.19	2.50	0.98	0.79	**126.05**
Ecoregion							
Pine Woodlands	196.69	32.38	75.44	2.75	0.49	1.05	**308.79**
Coastal Woodlands	17.18	2.76	11.98	1.37	0.21	1.55	**35.05**
Post Oak	66.78	14.98	15.90	1.32	0.66	0.39	**100.03**
Hackberry-Oak	31.38	- 1.01	0.31	0.54	0.20	0.03	**31.45**
Mesquite– Juniper	19.08	1.92	- 0.05	0.45	0.11	< 0.01	**21.51**
High Plains	- 0.40	- 0.92	- 0.27	< 0.01	< 0.01	< 0.01	**- 1.59**
Mountain	- 0.70	- 4.36	- 0.57	< 0.01	< 0.01	< 0.01	**- 5.60**

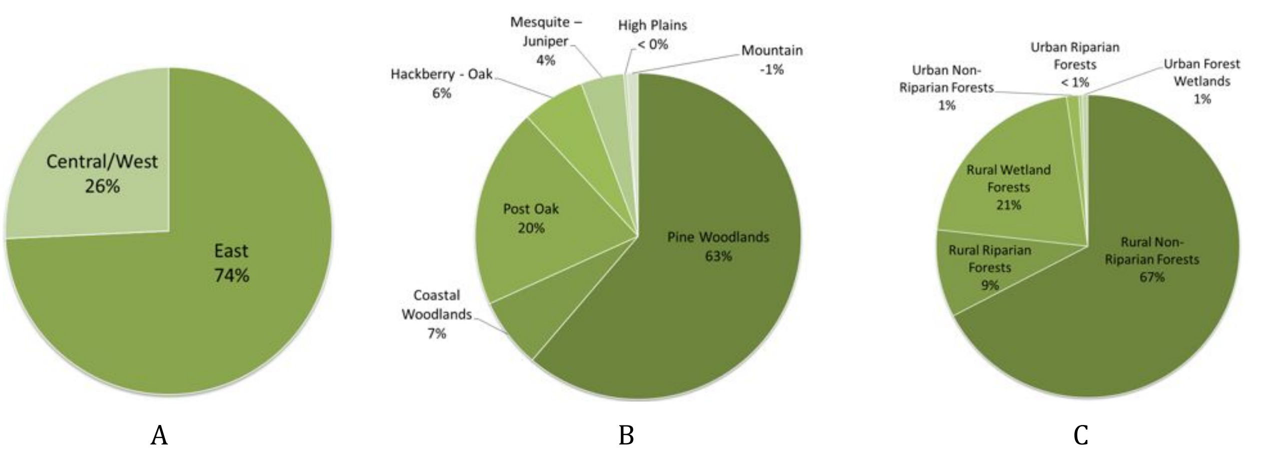


Figure 6. The percent contribution to water capture value by (A) region, (B) ecoregion, and (C) forest land cover type.

Water Filtration

Approximately 13.5 million acre-feet of water originates annually on non-riparian forests in Texas. These forests help purify the water, saving $268.6 million in avoided water treatment costs (Table 14). Riparian and wetland forests are even more efficient at filtering runoff water, providing an estimated $967.7 million and $3.0 billion, respectively. The total value of water filtration provided by Texas forestlands was $4.2 billion. The *Pine Woodlands* ecoregion provided the highest water filtration value, while the *High Plains* ecoregion provided the lowest.

Table 14. Water filtration function values (million $/year) by forest land cover type and region. Values may reflect slight discrepancies due to rounding.

Region	Rural Non-Riparian Forests	Rural Riparian Forests	Rural Wetland Forests	Urban Non-Riparian Forests	Urban Riparian Forests	Urban Forest Wetlands	**Total**
Texas	259.90	961.71	2,878.91	4.55	12.11	87.47	**4,204.64**
East	161.55	156.92	2,121.85	2.71	2.72	51.79	**2,497.53**
Central/West	98.35	804.79	757.06	1.84	9.39	35.68	**1,707.10**
Ecoregion							
Pine Woodlands	140.74	127.82	1,693.18	1.91	1.99	26.38	**1,992.02**
Coastal Woodlands	11.49	18.71	358.19	0.92	.83	34.78	**424.91**
Post Oak	48.34	104.92	583.82	0.92	4.61	18.74	**761.35**
Hackberry-Oak	22.93	302.61	57.24	0.36	2.20	2.49	**387.84**
Mesquite-Juniper	35.84	366.25	173.23	0.44	2.45	4.82	**583.04**
High Plains	0.01	14.04	6.74	0.00	0.02	0.24	**21.06**
Mountain	0.55	27.35	6.51	< 0.01	< 0.01	0.01	**34.42**

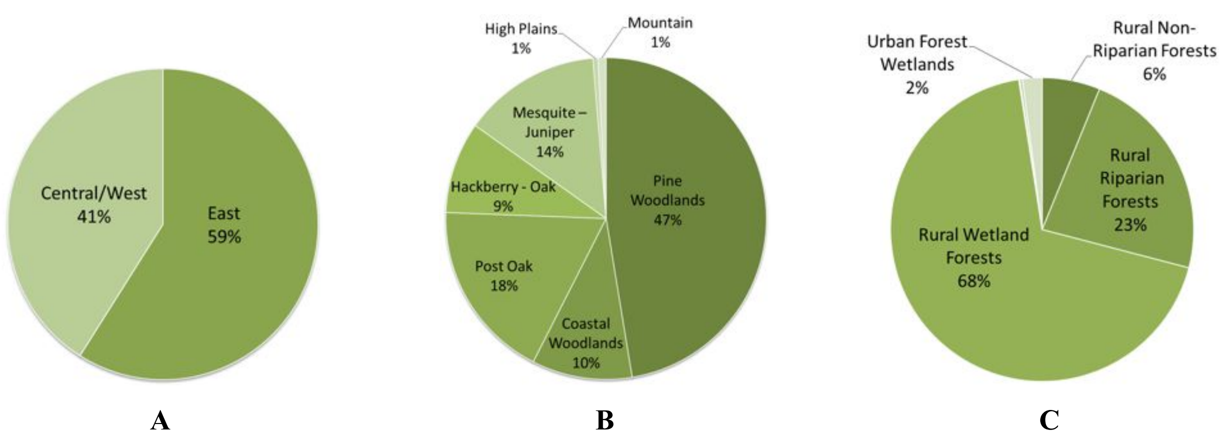


Figure 7. The percent contribution to water filtration value by (A) region, (B) ecoregion, and (C) forest land cover type.

Water Regulation / Disturbance Prevention

Forests function as green infrastructure, helping to regulate streamflow and prevent property damaging floods. While *Central/West Texas* has less precipitation and available water supply than the rest of the State, intense rain events make flash flooding more common. As a result, forests in this region are very important, accounting for over one-third of the total function value. Wetland forests cover less than 7% of the total forest area, but account for 85% of the total function value. The total value of this function was estimated at $8.5 billion (Table 15).

Table 15. Water regulation / disturbance prevention values (million $/year) by forest land cover type and region. Values may reflect slight discrepancies due to rounding.

Region	Rural Non-Riparian Forests	Rural Riparian Forests	Rural Wetland Forests	Urban Non-Riparian Forests	Urban Riparian Forests	Urban Forest Wetlands	**Total**
Texas	-	931.95	6,983.97	238.68	78.52	292.17	**8,525.28**
East	-	152.06	5,147.11	88.42	17.64	173.00	**5,578.23**
Central/West	-	779.89	1,836.85	150.25	60.88	119.17	**2,947.05**
Ecoregion							
Pine Woodlands	-	123.87	4,107.22	63.71	12.91	88.12	**4,395.83**
Coastal Woodlands	-	18.13	869.19	31.36	5.39	116.19	**1,040.27**
Post Oak	-	101.67	1,416.19	57.00	29.91	62.61	**1,667.38**
Hackberry-Oak	-	293.25	138.86	31.79	14.27	8.32	**486.48**
Mesquite-Juniper	-	354.92	420.22	54.57	15.91	16.10	**861.72**
High Plains	-	13.61	16.35	0.23	0.12	0.81	**31.11**
Mountain	-	26.51	15.94	0.02	< 0.01	0.03	**42.50**

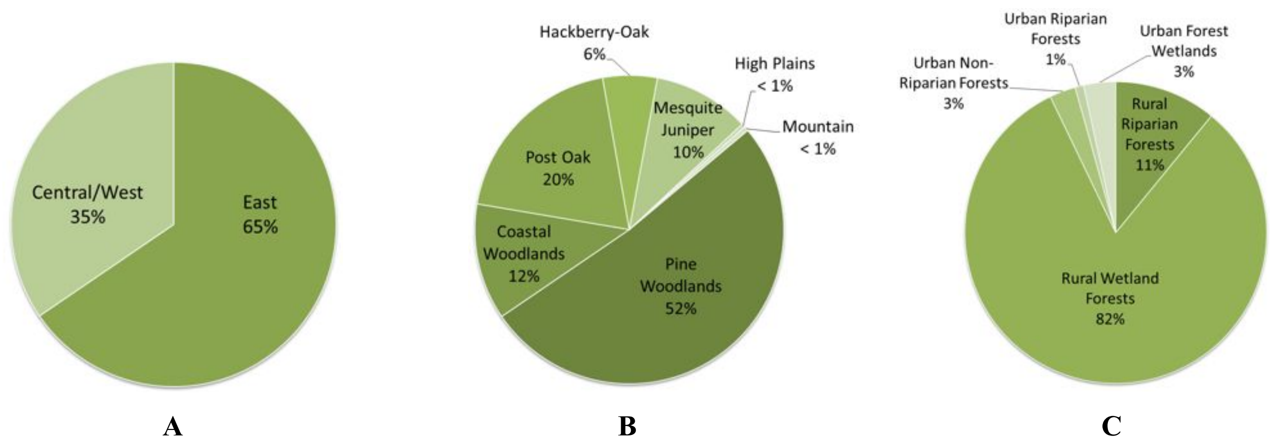


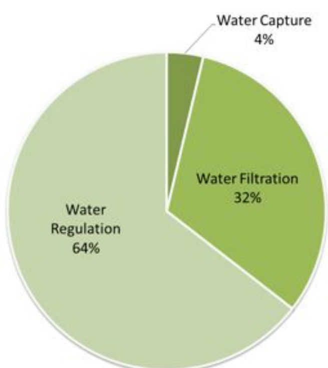
Figure 8. The percent contribution to water regulation by (A) region, (B) ecoregion, and (C) forest land cover type.

Total Forest Watershed Service Values

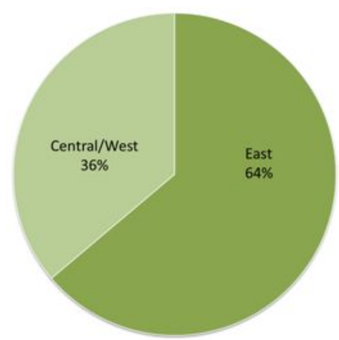
The total watershed service value provided by Texas forests was $13.2 billion, with 64% of this value made up by the water regulation function, followed by water filtration (32%) and water capture (4%). Rural wetland forests accounted for 75% of the total value, followed by rural riparian forests (15%). *East Texas* and the *Pine Woodlands* ecoregion represented 64% and 51% of the total value, respectively.

Table 16. Total watershed service values (million $/year) by forest land cover type and region. Values may reflect slight discrepancies due to rounding.

Region	Rural Non-Riparian Forests	Rural Riparian Forests	Rural Wetland Forests	Urban Non-Riparian Forests	Urban Riparian Forests	Urban Forest Wetlands	**Total**
Texas	589.95	1,939.41	9,965.61	249.66	92.29	382.66	**13,219.58**
East	388.15	347.60	7,360.50	95.07	21.04	227.01	**8,439.37**
Central/West	201.80	1,591.81	2,605.11	154.59	71.25	155.64	**4,780.20**
Ecoregion							
Pine Woodlands	337.43	284.07	5,875.83	68.36	15.39	115.55	**6,696.64**
Coastal Woodlands	28.67	39.60	1,239.35	33.66	6.44	152.52	**1,500.23**
Post Oak	115.12	221.56	2,015.90	59.25	35.18	81.74	**2,528.76**
Hackberry-Oak	54.31	594.85	196.41	32.69	16.67	10.84	**905.77**
Mesquite-Juniper	54.93	723.09	593.40	55.46	18.47	20.91	**1,466.27**
High Plains	-0.38	26.73	22.83	0.23	0.13	1.05	**50.59**
Mountain	-0.11	49.50	21.88	0.02	< 0.01	0.04	**71.33**



A



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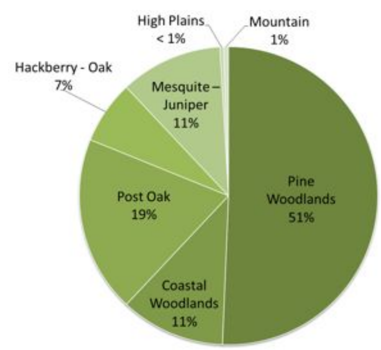


C

Figure 9. The percent contribution to total watershed value by (A) primary function; (B) region; and (C) ecoregion.

Discussion

This assessment was conducted as a broad, regional evaluation of forestlands in Texas. As such, per acre watershed service values were not differentiated among species group (except for negative water capture values associated with woody plant encroachment), stocking levels, or forest condition. Instead, watershed value was assessed primarily on their proximity to water. Regional and eco-regional watershed service values were largely based on the number of wetland and riparian forest acres within the respective areas, regardless of where they occurred within the State. Future valuation efforts may look to increase the resolution of the economic estimates used for these services to better account for the differences in forestland across the State.

As previously mentioned, all of the primary watershed functions performed by forests are inter-related and inter-dependent. In order to value these functions, they were separated based on their fundamental watershed service (water capture, water filtration, and water regulation/disturbance prevention). Economic estimates used in this assessment were comparable to other recent watershed regulating service value assessments (Escobedo, 2012; Costanza, 2006; Moore, 2009; Troy, 2012). While the Texas estimates were considered to be on the low end of the range ($211.8/acre), applying the lowest reported estimates to the representative forest areas in Texas ($96.5/acre) reduced the total assessed ecosystem service value by only 7.1 percent. Conversely, using the highest reported values for the same representative forest area ($1,139.0/acre) increased the total assessed ecosystem service value by 62.1%, suggesting that the watershed regulating service value may be under-estimated in Texas.

Soil stabilization provided by forests is a critical ecosystem service, preventing erosion from polluting water bodies, securing stream banks and flood plains, and maintaining soil productivity. Tree canopies intercept rainfall, lessening the impact of raindrops on soil held together by the forest leaf litter, tree roots, and other understory vegetation. Since many of the primary watershed functions of forests are so closely related to this service, and to avoid double counting, this function was valued based on soil productivity in the biodiversity chapter. Similarly, stream thermal protection, aquatic habitat of submerged tree roots, and detritus/organic material food sources provided by riparian forests, also support biodiversity.

A conservative approach was used in the valuation of ecosystem services provided by Texas forestlands. Rural, non-riparian forests play a critical role in regulating streamflow, stabilizing the timing and delivery of water across these landscapes. While these forest types undoubtedly provide a key service, an applicable value that could be applied across the entire cover type was not available given the broad, regional approach employed. Future valuation projects may look at applying water regulation values (based on stormwater management replacement construction costs) to rural forestlands in urban and community watersheds.

Conclusion

Watershed services provided by Texas forests were valued at more than $13 billion. While this amount is substantial, it is constantly at risk given the fact that forests are threatened by conversion, insects and disease, and natural disasters. Forest conversion, regardless of the type of new land use, results in substantial changes in watershed function. The complex interactions among natural hydrologic and ecological processes, land use, and water management underscore the need for conservation and integrated management of Texas forestlands. Given the challenges that Texas water providers, watershed managers, and forest landowners will face in the future, it will be essential that this interdependence be better understood and the fundamental importance of forests for each of these acknowledged. The vast majority (95%) of Texas forests are privately owned, so their future lies in the hands of individuals and corporations. Motivating them to take actions beneficial for water resources will require creative thought and investment.

Value of Forest Carbon Services

Introduction

Since the industrial revolution, human activities have released carbon dioxide (CO_2) into the atmosphere. As a result, human activities are altering the natural carbon cycle of the earth by adding CO_2 to the atmosphere and by removing natural carbon sinks (e.g., forests) that have the ability to remove CO_2 from the atmosphere. Because CO_2 is a primary greenhouse gas, there is increased attention toward reducing net carbon emissions in the U.S. and around the world. Additionally, there is interest in increasing the ability of natural systems to mitigate atmospheric carbon added as a result of human activities. Forests have a significant role in the global effort to mitigate greenhouse gases because their ability to utilize and accumulate atmospheric carbon into portions (or pools) within the forest is one of the most effective mechanisms for offsetting CO_2 emissions (U.S. EPA, 2005; Gonzales-Benecke et al., 2011; Sundquist, 2008; Sedjo, 1989). Carbon pools include above ground biomass, below ground biomass, carbon in live trees, carbon in the understory shrubs, litter layer, carbon in organic portion of soil, and carbon in standing dead material. Each of these pools adds up to significant quantities or stocks of carbon sequestered from atmospheric carbon. In addition, sequestered carbon can be “locked up” in wood products for decades or centuries providing an attractive long-term storage.

The annual incremental increase of carbon stored by forest (carbon accumulation) and subsequent long-term storage potential (stocks) of forests and forest products is becoming an increasingly valuable component in assessing the true value of forests. Forests have long been recognized as one of the best renewable, natural resources. Now, the importance of forests to provide carbon sequestration and other ecosystem services is emerging as a key economic value in the market place. A carbon market could be an important incentive for landowners to not only conserve forests and lessen the loss of forests through deforestation, but provide a mechanism to encourage management activities that promote forest health, vigor, and resiliency to environmental stressors (e.g., wildfire) that cause the release of stored carbon. This report quantifies carbon stored and the rate of accumulation in the various pools of Texas forests and woodlands.

Methods

Carbon Pools

All available FIA carbon pools were combined into five project-defined carbon pools (Table 17) that best describe the areas of interest to this study. These include: *live tree above ground*, *live understory above ground*, *total below ground*, *total dead*, and *soil organic*. The FIA carbon data were converted to per-acre amounts by project carbon pool and from tons (U.S.) to metric tons (t).

Table 17. Above ground (AG) and below ground (BG) carbon stock pools identified by this project and formed from a combination of one or more FIA carbon pools.

Carbon Pools	Description
Live Tree AG	Aboveground carbon in live trees
Live Understory AG	Carbon in aboveground live portion of seedlings, shrubs, and bushes
Total Live BG	Sum of live tree belowground and live understory belowground
Total Dead	Sum of down dead, standing dead, and litter carbon
Soil Organic	Carbon in organic soil to a depth of 1 meter
Total Carbon	Sum of live tree AG, live understory AG, total BG, total dead, and soil organic carbon

Annual Increment

Current literature was extensively reviewed to determine reasonable rates for the annual accumulation of carbon in the forests of Texas. The literature provided a broad-range of values with inconsistent consideration of standard carbon pools (Birdsey, 1992; Smith et al., 2006; Archer et al., 2004; Hughes et al., 2006; Huenneke et al., 2002; Hibbard et al., 2003; Norris et al., 2010). These differences reflect the climatic, edaphic, historic land use, and methods of determining carbon and carbon accumulation. Upon careful consideration of reported data, the values in Table 18 were selected to represent conservative accumulation rates for all live, above ground vegetation for the various forest types. Actual values are almost certainly higher as studies have shown the annual net ecosystem productivity for southern pine plantations to be as much a 3 tC/acre/year on highly productive sites in the southeast (Clark et al., 1999; Katul et al., 1999; Johnsen et al., 2001).

Table 18. Selected annual accumulation rates for total above ground live carbon by forest type.

Forest Type	Ton(US)/ac/yr	Metric tons/ac/yr
Pine Natural	1.43	1.30
Pine Planted	1.21	1.09
Hardwood-Pine	1.12	1.01
Hardwood-Upland	0.98	0.89
Hardwood-Bottomland	1.12	1.01
Hardwood-Riparian	1.21	1.09
Hardwood-Other	0.80	0.73
Juniper	0.94	0.85
Mesquite	0.83	0.75
Other	0.62	0.57

Valuation of Carbon Storage and Carbon Accumulation

There is a difference in the value of carbon storage and carbon accumulation. Much of the economic value of carbon storage in the forest ecosystem is lost if the vegetation is lost to wildfire, insects, disease, and extreme weather events or if the forest is converted to other uses. Therefore, the value of carbon storage is a snapshot at a given point in time. The value of carbon accumulation, on the other hand, is the value of the net annual fixation of carbon in a growing forest. A significant volume of studies exist that estimates the value of carbon based on an economic cost to society. This concept is often called the social cost of carbon. In this study, $22/tC was adopted as the value of carbon accumulated and stored in forests. As with all markets, the value of carbon will fluctuate over time. However, $22/tC is likely a conservative approximation of the long-term average. Refer to Appendix A for more discussion on methods to determine the social cost of carbon.

Results and Discussion

Carbon Stocks, Accumulation and Economic Value for Texas

Total carbon stocks and average carbon accumulation for all Texas forests are listed in Table 19. The total carbon stock estimated for all Texas forests was 2.3 billion tC on 62.4 million forested acres. Total annual economic value of this stock was $3.1 billion/year. The total carbon accumulation rate by all above ground, live vegetation for all Texas forests was 52.8 million tC/year with an annual economic value of more than $1.2 billion. Together, the total economic value of carbon stocks and carbon accumulation potential of Texas forests equaled $4.3 billion/year. The average total carbon stock estimated for all forests was 33.7 tC/ac. This ranged from 29.8 tC/ac for *Mesquite-Juniper* ecoregion to 45.7 tC/ac for *Pine Woodlands* ecoregion. The amortized, average total annual economic value of current carbon stocks was $49.8/acre/year and ranged from

$44.4 – $67.6/acre/year. The average total economic value of carbon accumulation for Texas forests was $18.6/acre/year and ranged from $12.5/acre/year for scrub hardwood forests types (other) in *Central/West Texas* to $28.6/acre/year for planted *Pine* forest types in *East Texas*. On average, the total annual forest carbon value was $68.4/acre/year.

Table 19. Total annual economic value of carbon stocks and carbon accumulation potential of Texas forests.

	[a]Forest Carbon (million tC)	Value (million $/yr)	Per acre (tC/ac/yr)	Value ($/ac/yr)
Carbon Stocks	2,101.94	3,108.23	33.67	49.79
Carbon Accumulation	[b]52.84	1,162.40	0.85	18.62
	Total	**4,270.63**	**Total**	**68.41**

[a]Across 62.4 million acres. [b]Accumulation is million tC/year

Carbon Stocks, Accumulation and Economic Value by Ecoregion

Texas forests hold more than 2.1 billion metric tons of carbon across 62.4 million acres throughout Texas (Table 20). The *Mesquite-Juniper* ecoregion was the largest ecoregion at 24.0 million acres with stocks at more than 655.7 million tC. This was 31.2% of all forest held carbon in Texas (Figure 10a). *Hackberry-Oak* and *Pine Woodlands* ecoregions provided the next highest carbon pools at 501.9 million tC (23.9%) and 456.5 million tC (21.7%), respectively. The smallest number of forested acres fell within the *Coastal Woodlands* ecoregion at 2.1 million acres. However, the *High Plains* ecoregion held the smallest amount of carbon at nearly 73.9 million metric tons or just 3.5% of the total forest held carbon stocks. An interesting note is that the *Pine Woodlands* ecoregion made, by far, the greatest contribution to *live tree above ground* carbon (170.5 million tC or 43.5%) which was twice as much as the (*Mesquite-Juniper* ecoregion (72.8 million metric tons or 18.5%), the next largest contributor (Figure 10b). The *Mesquite-Juniper* ecoregion held the greatest quantity of *soil organic* carbon at 451.8 million metric tons. However, when comparing the quantity of carbon stocks on a per acre basis, the *Pine Woodlands* ecoregion, at 45.7 tC/ac, contributed the most (Table 21). The *Coastal Woodlands* and *Post Oak* ecoregions also contained large stocks with about 37.5 tC/ac each. In addition, the *Pine Woodlands* ecoregion held 17.1 tC/ac in the *live tree above ground* carbon pool, which was more than double any other ecoregion except *Post Oak* (11.6 tC/ac).

The total tC accumulated annually is provided by forest type and ecoregion in Table 22. The *Mesquite-Juniper, Hackberry-Oak,* and *Pine Woodlands* ecoregions produced the greatest annual C accumulation at 17.7, 13.0, and 10.2 million tC/year valued at $3.9, $2.9, and $2.2 million/year, respectively. The *Pine Woodlands* ecoregion has the highest per acre value at $22.5/acre/year. Within this ecoregion, the *Pine* forest type accounted for 52.4% of annually accumulated C (5.3 million tC/year).

Table 20. Carbon stock (million tC) for each ecoregion by carbon pool.

Ecoregion	Forest Area (million acres)	Total Carbon	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Woodlands	9.98	456.55	170.58	11.48	37.71	61.73	175.04
Coastal Woodlands	2.00	81.74	19.22	2.52	4.12	8.61	47.27
Post Oak	5.86	229.63	67.74	6.90	14.34	28.42	112.23
Hackberry-Oak	15.29	501.86	57.46	23.81	14.40	52.69	353.50
Mesquite-Juniper	24.03	655.66	72.82	32.71	18.80	79.46	451.87
High Plains	2.34	73.92	2.24	3.75	0.88	5.22	61.83
Mountain	2.92	102.58	2.39	5.22	1.09	7.95	85.93
Total	**62.42**	**2,101.94**	**392.46**	**86.40**	**91.34**	**244.07**	**1,287.67**

A B

Figure 10. Comparison of (A) the percent at which forest in each ecoregion contribute to total forest carbon; and (B) the percent that each ecoregion contributes to the *live tree above ground* carbon pool.

Table 21. Carbon stock (tC/ac) by carbon pool for project defined ecoregions.

Ecoregion	Total Carbon	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Woodlands	45.72	17.08	1.15	3.78	6.18	17.53
Coastal Woodlands	40.93	9.63	1.26	2.06	4.31	23.67
Post Oak	39.20	11.56	1.18	2.45	4.85	19.16
Hackberry-Oak	32.82	3.76	1.56	0.94	3.44	23.11
Mesquite-Juniper	27.28	3.03	1.36	0.78	3.31	18.80
High Plains	31.58	0.96	1.60	0.38	2.23	26.41
Mountain	35.18	0.82	1.79	0.37	2.73	29.47

Table 22. Total tC accumulated per year by forest type and project ecoregion and their economic value.

	Pine Woodlands (10,000)	Coastal Woodlands (10,000)	Post Oak (10,000)	Hackberry-Oak (10,000)	Mesquite-Juniper (10,000)	High-Plains (10,000)	Mountain (10,000)	Total tC/year (10,000)	Annual Value (million $)	Annual Value ($/ac)
Pine	534.24	11.74	31.53	-	-	-	-	577.51	127.05	23.98
Oak-Pine	133.30	5.42	31.95	6.32	-	-	-	176.98	38.94	22.22
Hardwood-Upland	180.27	39.42	270.50	232.59	444.62	-	1.80	1,169.20	257.22	19.58
Hardwood-Bottom	115.01	26.41	36.07	25.17	16.77	0.68	-	220.12	48.43	22.22
Hardwood-Riparian	43.03	38.81	111.71	67.95	43.16	9.92	2.20	316.79	69.69	23.98
Hardwood-Other	7.50	13.14	2.35	18.81	20.02	-	1.85	63.67	14.01	16.06
Juniper	1.64	-	12.40	288.97	513.51	13.22	17.26	847.00	186.34	18.70
Mesquite	-	50.54	55.76	595.01	655.14	149.79	212.28	1,718.53	378.08	16.50
Other	4.91	5.81	9.18	64.25	80.61	12.03	17.03	193.82	42.64	12.88
Total 10,000 tC/yr	1,019.91	191.29	561.45	1,299.06	1,773.85	185.65	252.42	5,283.62	1,162.40	
Annual Value (million $)	224.38	42.08	123.52	285.79	390.25	40.84	55.53	1,162.40		
Annual Value ($/ac)	**22.46**	**19.33**	**20.22**	**17.57**	**17.72**	**16.59**	**16.34**	**18.62**		

Economic Value

Tables 23 and 24 present the total economic C value and C value per acre, respectively, held by each ecoregion's carbon pool. These values were calculated by multiplying the total metric tons of carbon held in each pool by $22/tC. The total economic contribution provided by the carbon stocks of Texas Forests is $46.2 billion. In other words, this is the social cost of carbon emissions should Texas forests be converted to other uses. The *Mesquite-Juniper* ecoregion, at more than 22.0 million acres, has carbon stocks valued at $14.4 billion. The *Hackberry-Oak* and *Pine Woodlands* ecoregions were valued at $11.0 billion and $10.0 billion respectively. The *Pine Woodlands* ecoregion provided the greatest dollar value per acre ($1,005.6/acre) of any other ecoregion with *Post Oak*, the second highest region at $826.9/acre.

Table 23. Economic value of total carbon stored by ecoregion and by carbon pool.

Ecoregion	Forest Acres (million)	Carbon Storage Value (million $)					
		Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Woodlands	9.98	10,044.08	3,752.86	252.62	829.63	1,357.99	3,850.98
Coastal Woodlands	2.00	1,798.29	422.91	55.34	90.61	189.49	1,039.94
Post Oak	5.86	5,051.78	1,490.35	151.83	315.40	625.16	2,469.04
Hackberry-Oak	15.29	11,041.01	1,264.11	523.93	316.78	1,159.10	7,777.08
Mesquite-Juniper	24.03	14,424.62	1,602.01	719.67	413.69	1,748.02	9,941.24
High Plains	2.34	1,626.15	49.22	82.48	19.41	114.88	1,360.16
Mountain	2.92	2,256.69	52.67	114.93	23.90	174.82	1,890.37
Total	**62.42**	**46,242.62**	**8,634.13**	**1,900.79**	**2,009.42**	**5,369.47**	**28,328.81**

Table 24. Economic value per acre of total carbon stored by ecoregion and by carbon pool.

Ecoregion	Total Carbon	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Woodlands	1,005.92	375.85	25.30	83.09	136.00	385.68
Coastal Woodlands	900.49	211.77	27.71	45.38	94.89	520.75
Post Oak	862.33	254.40	25.92	53.84	106.71	421.46
Hackberry-oak	721.93	82.66	34.26	20.71	75.79	508.52
Mesquite-Juniper	600.18	66.66	29.94	17.21	72.73	413.64
High-plains	694.69	21.03	35.23	8.29	49.08	581.06
Mountain	773.95	18.06	39.41	8.20	59.96	648.31

Tables 23 and 24 represent a snapshot of carbon stocks and their value. These values can also be amortized over a period of time (normally 20 years) to estimate the annual economic impact of current stocks. If amortized over 20 years as an annuity at 3 percent, the annual value of carbon stocks in all Texas forests is $3.1 billion. Table 25 shows the amortized annual economic value of total carbon stored by ecoregion and by carbon pool. Table 26 is the amortized annual economic value of carbon stocks averaged per acre for each ecoregion and carbon pool. The economic values for carbon accumulation for each ecoregion are presented in Table 22. For example, the *Pine Woodlands* ecoregion total carbon accumulation value was $224.4 million annually (Table 22) and averaged $22.5/acre/year (Table 22). Adding these values together with the amortized annual economic values for the *Pine Woodlands* ecoregion ($675.1 million/year or $67.5/acre/year), the total carbon value for the ecoregion is $899.5 million annually or $90.0/acre/year (Table 27).

Table 25. Amortized annual economic value of total carbon stored by ecoregion and carbon pool.

Ecoregion	Forest Acres (million)	Carbon Storage Value (million $)					
		Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Woodlands	9.98	675.12	252.25	16.98	55.76	91.28	258.85
Coastal Woodlands	2.00	120.87	28.43	3.72	6.09	12.74	69.90
Post Oak	5.86	339.56	100.18	10.21	21.20	42.02	165.96
Hackberry-Oak	15.29	742.13	84.97	35.22	21.29	77.91	522.74
Mesquite-Juniper	24.03	969.56	107.68	48.37	27.81	117.49	668.21
High-Plains	2.34	109.30	3.31	5.54	1.30	7.72	91.42
Mountain	2.92	151.69	3.54	7.72	1.61	11.75	127.06
Total	**62.42**	**3,108.23**	**580.35**	**127.76**	**135.06**	**360.91**	**1,904.14**

Table 26. The averaged amortized annual economic value by acre for each ecoregion and carbon pool.

Ecoregion	Total Carbon	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Woodlands	67.61	25.26	1.70	5.58	9.14	25.92
Coastal Woodlands	60.53	14.23	1.86	3.05	6.38	35.00
Post Oak	57.96	17.10	1.74	3.62	7.17	28.33
Hackberry-Oak	48.53	5.56	2.30	1.39	5.09	34.18
Mesquite-Juniper	40.34	4.48	2.01	1.16	4.89	27.80
High-Plains	46.69	1.41	2.37	0.56	3.30	39.06
Mountain	52.02	1.21	2.65	0.55	4.03	43.58

Following the same procedure, the annual total economic values of carbon stock and carbon accumulation for each ecoregion are as follows: *Pine Woodlands* = $899.5 million; Coastal *Woodlands* = $162.9 million; *Post Oak* = $463.1 million; *Hackberry-Oak* = $1,027.9 million; *Mesquite-Juniper* = $1,359.8 million; *High-Plains* = $150.1 million; *Mountain* = $207.2 million. Economic values for annual carbon accumulation per acre for each ecoregion ranged from $60.9 – $90.0/acre/year (Table 27).

Table 27. Total carbon value (stock plus accumulation) table for ecoregion.

Ecoregion	Carbon Stocks ($/ac/yr)	Carbon Accumulation ($/ac/yr)	Total Service Value ($/ac/yr)
Pine Woodlands	67.59	22.46	90.06
Coastal Woodlands	55.51	19.33	74.83
Post Oak	55.58	20.22	75.80
Hackberry-Oak	45.62	17.57	63.19
Mesquite-Juniper	44.03	17.72	61.75
High-Plains	44.40	16.59	60.99
Mountain	44.64	16.34	60.98

Carbon Stocks, Accumulation and Economic Value for East Texas

Carbon stocks held by the 43 East Texas counties of the pineywoods total 546.5 million metric tons (Table 28). The *Pine* forest type, at 253.3 million tC, holds more than twice the total carbon as the next highest forest type, *Hardwood–Upland*, at 112.9 million tC. This pattern holds true for the *Live tree above ground* carbon pool at 97.7 million tC for *Pine* versus 41.2 million tC for *Hardwood-Upland*. *Live tree above ground* and *soil organic* carbon pools stocked the greatest amount of C for *Pine*, both roughly equal. The top three forest types for total carbon were *Pine*, *Hardwood-Upland,* and *Hardwood-Bottom*. However, when compared on a per acre basis, the *Hardwood-Bottom* forest type held the most (52.7 tC/acre), followed by *Pine* at 48.4 tC/acre (Table 29). This matched previous studies that showed bottomland hardwoods to be the greatest carbon sinks of any other forest type. It is important to note that 75.9% of the total carbon was held in the *live tree above ground* and *soil organic* pools. Soil organic carbon is little impacted during sustainable forest management operations, and the *live tree above ground* pool is often used to produce long-lived carbon products (e.g. sawtimber) that may sequester carbon for centuries.

Table 28. Carbon stocks (million tC) by forest types and by carbon pool for *East Texas* region.

Project Forest Type	Forest Area (million acres)	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine	5.22	253.27	97.77	6.61	22.62	36.64	89.64
Oak-Pine	1.50	64.24	22.45	1.84	4.92	9.60	25.43
Hardwood-Upland	2.90	112.94	41.16	3.57	8.57	14.21	45.43
Hardwood-Bottom	1.41	75.19	29.45	0.83	5.94	8.54	30.43
Hardwood-Riparian	0.66	26.95	8.46	0.40	1.70	3.17	13.22
Hardwood-Other	0.25	9.30	1.42	0.19	0.31	0.80	6.57
Other	0.15	4.61	0.55	0.21	0.15	0.50	3.20
Total	**12.08**	**546.50**	**201.27**	**13.65**	**44.20**	**73.45**	**213.93**

Table 29. Metric tons of carbon per acre by forest types and by carbon pool for *East Texas* region.

Project Forest Type	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Total	48.38	18.68	1.26	4.32	7.00	17.12
Oak-Pine	42.61	14.89	1.22	3.26	6.37	16.87
Hardwood-Upland	38.86	14.16	1.23	2.95	4.89	15.63
Hardwood-Bottom	52.77	20.67	0.58	4.17	5.99	21.35
Hardwood-Riparian	41.14	12.91	0.62	2.60	4.83	20.18
Hardwood-Other	37.19	5.70	0.76	1.26	3.18	26.29
Other	30.09	3.61	1.37	0.95	3.26	20.90

FIA data also provides carbon pool estimates for the *Pine* forest type by stand origin (natural or planted). Pine carbon stocks by stand origin were evaluated for only the *East Texas* region (Table 30). Both were equivalent acres, (2.6 million acres); however, natural pine contained greater carbon stocks at 149.3 million tC than planted pine at 103.9 million tC or, 57.5 versus 39.4 tC/acre (Table 31). This result is likely due to the fact that natural stands tend to have more woody stems per acre, but less carbon per stem (tree), than planted stands. In other words, planted stands contain less carbon stocks overall, but concentrate that carbon on fewer trees. The carbon in planted trees is more likely to be used for long-lived products such as sawtimber and may be sequestered indefinitely. In addition, natural stands, if left unmanaged, may eventually be at higher risk of loss from wildfire, insects and disease than planted stands due to decreased vigor resulting from overly-dense conditions. A loss of the trees within these stands would release carbon back into the atmosphere.

Table 30. Carbon (million tC) for *Pine* forest types in the *East Texas* region by FIA stand origin (natural or artificial) and by project carbon pool.

Stand Origin	Forest Area (million acres)	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Natural	2.59	149.30	66.26	2.85	14.97	20.91	44.31
Planted	2.63	103.97	31.51	3.76	7.64	15.73	45.33
Total	**5.22**	**253.27**	**97.77**	**6.61**	**22.62**	**36.64**	**89.64**

Table 31. Carbon per acre (tC/ac) for pine forest types in the *East Texas* region by FIA stand origin (natural or artificial) and by project carbon pool.

Stand Origin	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Natural	57.49	25.52	1.10	5.77	8.05	17.06
Planted	39.41	11.94	1.43	2.90	5.96	17.18
Average	**48.38**	**18.68**	**1.26**	**4.32**	**7.00**	**17.12**

Economic Value

Tables 32 and 33 present the total amortized annual economic C value and C value per acre, respectively, held by each forest type in the *East Texas* region and by carbon pool. The total annual economic contribution was $808.1 million. The *Pine* forest type, by far, contributed the greatest total annual value at $374.5 million, more than twice the next highest forest type, *Hardwood-Upland*. However, when considering value per acre, *Hardwood-Bottom* forest type ranked first at $78.0/acre followed closely by *Pine* at $71.5/acre.

Table 32. Amortized annual economic value of total carbon stored by forest type and by carbon pool for *East Texas* region.

Project Forest Type	Forest Area (million acres)	Total Carbon (million $)	Live Tree AG (million $)	Understory AG (million $)	Total BG (million $)	Total Dead (million $)	Soil Organic (million $)
Pine	5.22	374.53	144.58	9.77	33.44	54.18	132.56
Oak-Pine	1.50	94.99	33.20	2.72	7.27	14.20	37.60
Hardwood-Upland	2.90	167.01	60.86	5.28	12.67	21.01	67.19
Hardwood-Bottom	1.41	111.19	43.55	1.23	8.78	12.63	45.00
Hardwood-Riparian	0.66	39.85	12.51	0.60	2.52	4.68	19.55
Hardwood-Other	0.25	13.75	2.11	0.28	0.46	1.18	9.72
Other	0.15	6.82	0.82	0.31	0.21	0.74	4.74
Total	**12.08**	**808.13**	**297.63**	**20.18**	**65.36**	**108.62**	**316.34**

The total tC accumulated annually by forest types in the *East Texas* region and their annual economic contribution are provided in Table 34. Naturally regenerated pine stands, at 2.6 million acres, had the highest accumulation rate and thus rank first in economic value at $74.3 million/year followed by planted *Pine* and *Hardwood-Upland* forest types at $63.5 and $56.9 million/year respectively (Table 34).

Table 33. Amortized annual economic value of total carbon stored in dollars (US) per acre by forest type and by carbon pool for *East Texas* region.

Project Forest Type	Total Carbon	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine	71.54	27.62	1.87	6.39	10.35	25.32
Oak-Pine	63.01	22.02	1.80	4.82	9.42	24.94
Hardwood-Upland	57.47	20.94	1.82	4.36	7.23	23.12
Hardwood-Bottom	78.03	30.56	0.86	6.16	8.86	31.58
Hardwood-Riparian	60.83	19.09	0.91	3.84	7.14	29.84
Hardwood-Other	54.99	8.43	1.13	1.86	4.71	38.87
Other	44.50	5.34	2.03	1.40	4.83	30.90

Table 34. Total acres, carbon accumulation rates, total carbon accumulated by all above ground, live vegetation per year, and annual economic value for each project forest type in *East Texas* region.

Forest Type	Area (million acres)	Rate (tC/ac/yr)	Total Carbon (million tC/yr)	Value (million $)	Value ($/ac)
Pine Natural	2.59	1.30	3.38	74.27	28.60
Pine Planted	2.63	1.09	2.88	63.27	23.98
Hardwood/Pine	1.50	1.01	1.52	33.50	22.22
Hardwood-Upland	2.90	0.89	2.59	56.90	19.58
Hardwood-Bottom	1.41	1.01	1.44	31.66	22.22
Hardwood-Riparian	0.66	1.09	0.71	15.71	23.98
Hardwood-Other	0.25	0.73	0.18	4.01	16.06
Other	0.15	0.57	0.09	1.92	12.54
Total	12.08		12.24	269.25	22.19

Carbon Stocks, Accumulation and Economic Value for Central and West Texas

Carbon stocks held by the *Central/West Texas* region totaled more than 1.5 billion metric tons for the 50.3 million acre region (Table 35). Unlike the *East Texas* region, which had equal *live tree above ground* and *soil organic* carbon pools, all forest types in *Central/West Texas* region had a disproportionately large percentage of carbon tied up in *soil organic* (50-80%) and relatively little carbon in the *live tree above ground pool* (1-23%) for the three forest types (*Mesquite*, *Hardwood-Upland*, *Juniper*) with the greatest total carbon stocks. Carbon stocks per acre for each forest type (Table 36) ranged from 26.6 tC/acre (*Juniper*) to 49.4 tC/acre (*Pine*). The two largest forest types, *Mesquite*, and *Hardwood-Upland* have similar carbon stocks per acre, with most of it being in the *soil organic* pool. This suggests that management practices that reduce, but do not eliminate tree cover on these acres could provide multiple benefits while not significantly impacting carbon stocks.

Table 35. Carbon (million tC) held by each project carbon pool by forest types for *Central/West Texas* region.

Project Forest Type	Area (million acres)	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Total	0.06	3.12	1.21	0.07	0.28	0.49	1.07
Oak-Pine	0.24	9.41	2.82	0.29	0.62	1.55	4.13
Hardwood-Upland	10.24	298.50	69.74	13.93	15.47	39.43	159.94
Hardwood-Bottom	0.75	28.73	7.40	0.48	1.49	3.26	16.11
Hardwood-Riparian	2.25	81.30	20.95	1.43	4.27	9.22	45.42
Hardwood-Other	0.62	23.50	3.38	0.87	0.80	2.10	16.36
Juniper	9.97	265.03	34.12	13.25	9.20	56.56	151.90
Mesquite	22.94	758.76	50.65	37.65	14.30	53.79	602.36
Other	3.25	87.09	0.92	4.78	0.72	4.22	76.45
Total	**50.35**	**1,555.44**	**191.19**	**72.75**	**47.14**	**170.61**	**1,073.75**

Table 36. Metric tons of carbon per acre by forest types and by carbon pool for *Central/West Texas* region.

Project Forest Type	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Total	49.42	19.21	1.10	4.41	7.74	16.95
Oak-Pine	38.44	11.52	1.20	2.52	6.34	16.87
Hardwood-Upland	29.18	6.82	1.36	1.51	3.85	15.63
Hardwood-Bottom	38.08	9.81	0.64	1.97	4.31	21.35
Hardwood-Riparian	36.11	9.30	0.64	1.90	4.10	20.18
Hardwood-Other	37.77	5.44	1.40	1.28	3.37	26.29
Juniper	26.60	3.42	1.33	0.92	5.68	15.24
Mesquite	33.11	2.21	1.64	0.62	2.35	26.29
Other	26.82	0.28	1.47	0.22	1.30	23.55

Economic Value

Tables 37 and 38 present the total amortized annual economic C value and C value per acre, respectively, held by each forest type in the *Central/West Texas* region and by carbon pool. The total annual economic contribution provided by the carbon stocks of forests in this region was $2.3 billion. Again, *Mesquite* had the highest value of $1.1 billion with more than $890.7 million in the *soil organic* pool alone.

The total metric tons of C accumulated annually by forest types in *Central/West Texas* region and their annual economic contribution are provided in Table 39. Total economic value for this region was $894.3 million annually. The *Mesquite* forest type, which has only a moderate carbon accumulation rate, contributed the highest annual value with more than $378.1 million.

Table 37. Amortized annual economic value of total carbon by forest type and pool for *Central/West Texas* region.

Project Forest Type	Area (million acres)	Total (million $)	Live Tree AG (million $)	Understory AG (million $)	Total BG (million $)	Total Dead (million $)	Soil Organic (million $)
Pine Total	0.06	4.62	1.79	0.10	0.41	0.72	1.58
Oak-Pine	0.24	13.91	4.17	0.43	0.91	2.29	6.10
Hardwood-Upland	10.24	441.41	103.12	20.60	22.87	58.30	236.51
Hardwood-Bottom	0.75	42.49	10.94	0.71	2.20	4.81	23.82
Hardwood-Riparian	2.25	120.22	30.97	2.12	6.32	13.64	67.17
Hardwood-Other	0.62	34.75	5.00	1.28	1.18	3.10	24.19
Juniper	9.97	391.91	50.46	19.59	13.61	83.64	224.63
Mesquite	22.94	1,122.01	74.90	55.68	21.14	79.55	890.74
Other	3.25	128.78	1.36	7.07	1.06	6.24	113.05
Total	50.35	2,300.10	282.72	107.58	69.70	252.29	1,587.80

Table 38. Amortized annual dollars (US) per acre by forest types and by carbon pool for *Central/West Texas* region.

Project Forest Type	Total	Live Tree AG	Understory AG	Total BG	Total Dead	Soil Organic
Pine Total	73.08	28.41	1.63	6.52	11.45	25.07
Oak-Pine	56.85	17.03	1.77	3.73	9.38	24.94
Hardwood-Upland	43.15	10.08	2.01	2.24	5.70	23.12
Hardwood-Bottom	56.31	14.50	0.94	2.92	6.38	31.58
Hardwood-Riparian	53.40	13.76	0.94	2.81	6.06	29.84
Hardwood-Other	55.85	8.04	2.06	1.89	4.98	38.87
Juniper	39.33	5.06	1.97	1.37	8.39	22.54
Mesquite	48.97	3.27	2.43	0.92	3.47	38.87
Other	39.66	0.42	2.18	0.33	1.92	34.82

Table 39. Total acres, carbon accumulation rates, total carbon accumulated by all above ground, live vegetation per year, and annual economic value for each project forest type in *Central/West Texas* region.

Forest Type	Area (million acres)	Rate (tC/ac/yr)	Total Carbon (million tC/yr)	Value (million $)	Value ($/ac)
Pine	0.06	1.30	0.07	1.51	23.98
Hardwood / Pine	0.24	1.09	0.25	5.44	22.22
Hardwood-Upland	10.24	0.89	9.11	200.32	19.58
Hardwood-Bottom	0.75	1.01	0.76	16.76	22.22
Hardwood-Riparian	2.25	1.09	2.45	53.98	23.98
Hardwood-Other	0.62	0.73	0.45	9.99	16.06
Juniper	9.97	0.85	8.47	186.34	18.70
Mesquite	22.94	0.75	17.19	378.08	16.50
Other	3.25	0.57	1.85	40.72	12.54
Total	**50.35**		40.60	893.14	17.76

Conclusion

As reported in Table 40, the total annual value of carbon stocks held across all carbon pools and the value of the carbon accumulation rate by Texas forests was $3.1 billion and $1.2 billion, respectively. This represented a total carbon ecosystem service contribution to the citizens of Texas of $4.3 billion annually. The loss of current stocks would equate to the social costs of carbon emissions of more than $46.2 billion. The forests of East Texas provide an annual carbon stock and sequestration service valued at almost $1.1 billion in addition to the value of all other ecosystem goods and services provided. The *Central/West Texas* region, with a much larger land base, provided a carbon stock and sequestration service to society valued at approximately $3.2 billion annually.

Table 40. Total annual economic value of carbon stocks and accumulation potential of Texas' forests by region.

Region	Area (million acres)	Carbon Stocks (million tC)	[a]Amortized Stock Value (million $)	Accumulation Rate (million tC/yr)	Accumulation Value (million $)	**Total (million $)**	**Average ($/ac/yr)**
Texas	62.42	2,101.94	3,108.23	52.84	1,162.40	4,270.63	68.41
East	12.08	546.50	808.13	12.24	269.25	1,077.39	89.13
Central/West	50.35	1,555.44	2,300.10	40.60	893.14	3,193.24	63.44
Ecoregion							
Pine Woodlands	9.98	456.55	675.12	10.20	224.38	899.50	90.08
Coastal	2.00	81.74	120.87	1.91	42.08	162.96	79.85
Post Oak	5.86	229.63	339.56	5.61	123.52	463.08	78.18
Hackberry-Oak	15.29	501.86	742.13	12.99	285.79	1,027.92	66.09
Mesquite-Juniper	24.03	655.66	969.56	17.74	390.25	1,359.81	58.06
High-Plains	2.34	73.92	109.30	1.86	40.84	150.15	63.29
Mountain	2.92	102.58	151.69	2.52	55.53	207.22	68.36

[a]Amortized over 20 years as an annuity at 3 percent.

The *Mesquite-Juniper* ecoregion covers more than 22.0 million acres and provides carbon stock and accumulation services totaling more than $1.0 billion dollars annually. The carbon stock and accumulation service is substantial in this region. However, because the predominant tree species in this area, juniper (*Juniperus* sp.) and mesquite (*Prosopis* sp.), are generally considered nuisance plants encroaching upon range systems, the economic value of carbon sequestration provided in this ecoregion should be carefully balanced with any loss of value from other ecosystem services (e.g., watershed regulating, biodiversity) that would have otherwise been provided by the native (historic) ecosystem.

As thoroughly discussed in Appendix A, this study adopted $22/tC ($6.0/tCO_2e) as the social cost of sequestered carbon. This value was based upon a recent report by Forest Trends (Peters-Stanley and Hamilton 2012) which continually tracks the status and trend of the global voluntary carbon market. The assumed economic value of carbon is comparable to the values adopted by popular reports from the southern U.S. of $22/tC and $19.5/tC reported by Moore et al., (2010) and Timilzina (2012) respectively. However, a greatly varied range for carbon value (from $5.5/tC – 322.4/tC) can be found in the literature. Changing the assumed value of sequestered carbon to $5 or $70/tC had only a 3.2% negative and 9.2% positive impact to the total value of all ecosystem services provide by forests in Texas.

Value of Forest Biodiversity Services

Introduction

The forests of Texas are biologically rich and diverse. They provide a robust ecological system, hosting a multitude of life forms intertwined with non-living chemical and physical factors in the environment. Forests provide living space for plants and animals, as well as breeding and nursery grounds for game species. Diverse forest systems remain fairly stable and productive, and are at reduced risk to pest and disease outbreaks. This biodiversity is a source of value in forests. Biodiversity is defined as "the variability among living organisms from all sources, including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (CBD, 1992). In short, biodiversity indexes species richness (the number of different species present in a given area), their relative abundance, composition, and presence/absence of key species (Hooper et al., 2005).

Biodiversity may be considered a valuable resource for the single reason that it underpins all ecosystem functions and concomitant ecosystem services (e.g., carbon sequestration, water filtration, etc.) that are essential in supporting human existence (Christie et al., 2006; Costanza et al., 1997; Daily, 1997; MA, 2005; Sachs et al., 2009; Hooper et al., 2005). This chapter assesses the economic contribution of forest biodiversity, illustrating the importance of biologically diverse forests and the ecosystem services they provide. A monetary value placed on biodiversity may provide decision-makers with quantitative data to estimate the costs and benefits of programs intended to conserve, alter, or eliminate forest biodiversity.

Methods

Ecosystem Services Considered under Biodiversity Valuation

Numerous studies are available that report the value of biodiversity, but use varying definitions for biodiversity services. It seems that the valuation of biodiversity is one of the most significant and quickly evolving areas of research, likely due to the escalating need to build more comprehensive representation of ecological values for policy formulation and the decision making process (Turner et al., 2003). To simplify efforts to estimate the biodiversity value of Texas' forests, many services were grouped instead of being assessed individually as previous studies have done (de Groot et al., 2002; Liu et al., 2010; Moore, 2009; Salles, 2011; Tilman, 1997). In the context of this assessment, biodiversity services are defined as the contribution towards the conservation of species communities in their natural forest habitat such that all species within the forest have the ability to co-evolve and hence interact with each other. Under this definition, forest biodiversity services considers, among other factors, the functions of distribution (habitat/refugia), representation (richness), sustainability, pollination, soil formation, acre/area requirements, genetic resource, medicinal resource (drugs and pharmaceuticals) and others that are often addressed individually. Biodiversity services were assessed for the State, two broad regions, and seven ecoregions.

Cost of Forest Conservation

The largest component of the value of forest biodiversity can be considered to be the cost of conservation. That is, the total costs required to keep forests in forests and prevent permanent land-use change. The cost of conservation adequately conveys the non-market, life supporting, and intrinsic values of forest biodiversity often excluded from popular valuation methods such as the Total Economic Valuation (TEV) method and avoids double-counting the benefits of biodiversity. The cost of conservation can be measured in a number of ways. A particularly useful measure is to consider the related cost of deforestation. Deforestation, the permanent conversion of forest to some other land use, represents a cumulative loss from forest biodiversity services which has been shown equivalent to 1% to 7% of the gross domestic product (GDP) (Lewandrowski et al. 1999; Wu et al. 2010). This protocol is a particularly attractive method because it directly correlates the increased pressures placed upon forest resources as GDP increases. That is, as the quantity of goods and services produced within the State grow and strengthen, greater pressure is placed on natural resources, thus increasing the scarcity and/or potential loss of biologically diverse ecosystems. This, in turn, places greater monetary and intrinsic value on the ecosystem service. For this analysis, a conservative value of 1% of Texas' Gross State Product (GSP) was used as the base value of forested ecosystems to provide the necessary biodiversity needed for human well-being.

Assessing Ecologically Important Areas

Forests are key to providing ecological diversity essential for numerous goods and services to society. However, some areas may have additional contributions towards biodiversity than those defined by the base value. It is important to assess these "hotspots" of ecological importance so that policy makers may have the appropriate data to prioritize opportunities for avoiding potential impacts on these higher-value areas before loss occurs. For these reasons, the Regional Ecological Assessment Protocol (REAP) *Composite* information was included in this assessment. REAP is an ecoregional assessment geospatial dataset developed by the U.S. Environmental Protection Agency, Region 6 (Osowski et al., 2011).

The FIA geospatial forestland layer was compared to REAP's composite layer to estimate the number of forest acres falling within REAP's top 10% level of ecologically significant acres. Current literature presents a hugely broad range of associate economic values and/or costs for conserving ecologically significant areas (Hooper et al., 2005). Most values reflect a study group's Willingness to Pay (WTP) for conserving and/or protecting habitat of threatened or endangered species. These values vary greatly depending upon region and species, and range from $0 to greater than $10,000/acre/year (Loomis and Ekstrand 1998; Mendoza-González et al. 2012; Mullan and Kontoleon 2008; Elodie Brahic and Jean-Philippe Terreaux 2000; Polasky et al. 2001; Ando et al. 1998; Huang and Kronrad 2001). Mullan and Kontoleon (2008) report the global average opportunity cost of conserving forest biodiversity to be $209 acre/year, reflecting the costs to society if the product (in this case, ecosystem service/function) is lost. However, they also report that case studies estimate the opportunity costs of protecting forest biodiversity to range from $24 - $250 in the U.S. For the purposes of this report, the conservative value of $51.75 acre/year was assigned to the top 10% ecologically significant acres ("hotspots"). Not only does this value fall on the conservative end of the reported range, but this value is validated from comparable, published Willingness To Pay (WTP) values (Czajkowski et al., 2009) (Kroeger et al., 2012) and should conservatively represent the acceptable cost of conserving forest biodiversity in ecologically significant areas.

Results

Texas GSP is estimated at $1.45 trillion (USGov, 2012). Thus, the base value of forest ecosystems that provide the necessary biodiversity needed for human well-being is estimated to be $14.5 billion annually ($232/acre/year). The forests in the *East Texas* region provide $2.8 billion (19%), while forests in *Central/West Texas* provide $11.7 billion (81%) of this value (Table 41). The *Mesquite–Juniper* ecoregion ranked highest, with base services valued at $5.6 billion, while the *Coastal Woodlands* ecoregion ranked the lowest at $463.3 million.

Texas had 6.3 million acres that fell within the top 10% ecologically important acres as defined by REAP, providing an additional annual ecosystem service value of $326.1 million/year (Table 42). The *East Texas* region had nearly one million acres in this category valued at $50.5 million/year. The *Central/West Texas* region had 5.3 million acres falling within the top 10% valued at $275.6 million/year. Together, the base biodiversity and ecologically important values provided a total annual economic value of $14.8 billion to Texas (Table 43) which is equivalent to $237.2/acre/year. The *East Texas* region and *Central/West Texas* regions were valued at $2.9 billion and $11.9 billion annually, respectively.

Table 41. Base economic contribution of forest-based biodiversity services by region, rural and urban areas. Values per year and assume that forests' base biodiversity services are valued at $232/acre.

	Acres (million)				Biodiversity Base Service Value (million $/yr)		
Region	Total	Forested	Rural Forested	Urban Forested	Total Value	Rural Value	Urban Value
Texas	169.46	62.42	61.84	581,430.18	**14,482.44**	**14,347.55**	**134.89**
Region							
East	21.64	12.07	11.85	227,459.31	**2,801.12**	**2,748.35**	**52.77**
Central/West	147.82	50.35	50.00	353,970.87	**11,681.31**	**11,599.19**	**82.12**
Ecoregion							
Pine Woodlands	15.21	9.98	9.84	149,062.58	**2,316.51**	**2,281.93**	**34.58**
Coastal Woodlands	10.88	2.00	1.89	102,217.40	**463.30**	**439.59**	**23.71**
Post Oak	21.56	5.86	5.71	150,214.59	**1,359.12**	**1,324.27**	**34.85**
Hackberry-Oak	35.16	15.29	15.22	69,690.65	**3,548.13**	**3,531.96**	**16.17**
Mesquite-Juniper	43.33	24.03	23.92	109,378.51	**5,575.82**	**5,550.44**	**25.38**
High Plains	25.63	2.34	2.34	826.20	**543.08**	**542.88**	**0.19**
Mountain	17.69	2.92	2.92	40.25	**676.47**	**676.46**	**0.01**

Table 42. Quantity of forested acres falling into the top 10% of ecologically important areas as defined by REAP and their annual ecosystem services value by region.

	Acres				Biodiversity "Hotspot" Service Value (million $/yr)		
Region	Total 10% (millions)	Forested 10% (millions)	Rural 10% (millions)	Urban 10%	Total Value	Rural Value	Urban Value
Texas	12.77	6.30	6.27	30,591.91	**326.07**	**324.49**	**1.58**
Region							
East	1.44	0.97	0.97	6,649.37	**50.45**	**50.10**	**0.34**
Central/West	11.33	5.33	5.30	23,942.54	**275.63**	**274.39**	**1.24**
Ecoregion							
Pine Woodlands	1.06	0.81	0.81	5,587.88	**41.99**	**41.70**	**0.29**
Coastal Woodlands	0.83	0.16	0.16	2,752.58	**8.42**	**8.27**	**0.14**
Post Oak	1.71	0.71	0.70	10,441.19	**36.84**	**36.30**	**0.54**
Hackberry-Oak	2.13	1.18	1.18	1,695.54	**60.90**	**60.81**	**0.09**
Mesquite-Juniper	5.47	3.24	3.23	10,110.94	**167.86**	**167.34**	**0.52**
High Plains	0.67	0.09	0.09	3.34	**4.44**	**4.44**	**0.00**
Mountain	0.90	0.11	0.11	0.44	**5.63**	**5.63**	**0.00**

Discussion

Texas is a unique state, with substantial differences in biodiversity from the coastal woodlands along the Gulf to the arid mountain ranges of West Texas. This diverse landscape presents substantial challenges in assigning a standard biodiversity base value for the State's forestlands. As such, the conservative base value should adequately reflect the average across all ecoregions. Some areas may warrant a higher dollar value, while others will reflect a lower value. For example, because predominant forest cover is considered by many to be a nuisance resulting from land-use change and fire suppression, some may question the biodiversity value placed upon the *Mesquite-Juniper* ecoregion. While this area may have a much greater biodiversity value if managed towards its native range ecosystem, it still has value for biodiversity.

Table 43. Total annual value of forest biodiversity service in Texas by region.

Region	Total (million $/yr)	Rural (million $/yr)	Urban (million $/yr)
Texas	14,808.51	14,672.04	136.47
Region			
East	2,851.57	2,798.46	53.11
Central/West	11,956.94	11,873.58	83.36
Ecoregion			
Pine Woodlands	2,358.50	2,323.63	34.87
Coastal Woodlands	471.72	447.86	23.86
Post Oak	1,395.96	1,360.57	35.39
Hackberry-Oak	3,609.03	3,592.77	16.26
Mesquite-Juniper	5,743.68	5,717.78	25.90
High Plains	547.52	547.32	0.19
Mountain	682.10	682.09	0.01

The base value of biodiversity services ($232/acre/year) used in this assessment was conservative compared to other similar values reported in the literature. Lewandroski et al., (1999), estimated the opportunity costs of forest biodiversity conservation to be approximately $626/acre/year. Others have reported expenditures on biodiversity conservation in the U.S. from $100 (Richie and Holmes, 2001) to $1,131/acre/year (Wilson et al., 2007) using a similar assessment. The base value also compares favorably to studies that assess biodiversity services separately. Moore et al., (2009) reported $261/acre/year (2010 USD) and $191/acre/year (2010 USD) for habitat/refugia (in mid to high rare species abundant forests) and pollination, respectively. Similarly, Moore et al., (2009) reported a value of $212/acre/year for the value of pollination plus habitat when considering only the lowest value placed on low rare species abundant forests of $28/acre/year (all adjusted to 2011 dollars). This estimate used in this assessment falls substantially lower than Liu et al., (2010) who reported forest biodiversity values (pollination + habitat/refugia) of $1,085/acre/year (2010 USD) estimated from European studies, and Costanza et al., (1997) that value biodiversity in temperate forests at $1,050/acre/year (2010 USD). Considering the range of economic values reported in the current literature, lowering the adopted base value from $232 to $130/acre/year reduces the overall assessed service value by 6.8 percent. Conversely, increasing the assumed base value from $232 to $430/acre/year, increased the overall assessed service value by 13.3 percent.

Other ecologically important areas for biodiversity services include riparian buffers and wetlands. While some of these areas are counted as "hotspots," ideally, all of these forest types could also be stacked upon the base biodiversity value to highlight their importance to maintaining biologically diverse and resilient systems. However, these values are also tightly associated with ecosystem services dealing with watershed protection assessed in a separate chapter and are omitted here to avoid double counting. Although forest biodiversity science has improved significantly in recent years (Rodrigues et al., 2003), a great amount of research effort is still required to fully quantify the total service and optimized value to society. The process of thoroughly evaluating economic cost and benefits of forest biodiversity is extremely complex, multi-dimensional (Mullan & Kontoleon, 2008) and is, to date, outside the realm of current scientific knowledge, though many different frameworks have been proposed.

Value of Forest Cultural Services

Introduction

Forests provide people with important opportunities for spiritual enrichment, mental development, and leisure. They serve as critical sources of science, culture, art and education. People enjoy the scenery. They gain knowledge about nature, generate satisfaction derived from endowing future generations with forest resources, and satisfy their needs from their interactions with forestlands. This is the more emotive side of forestry, involving memories, emotions, and senses. These elements are normally referred to as cultural services. The Millennium Ecosystem Assessment (MEA, 2005), an international assessment of the consequences of ecosystem change for human well-being, defined cultural services as "the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience." Cultural services provided by forest ecosystems are normally less tangible than other forest ecosystem services and goods such as regulating, functioning, and provisioning services. MEA and a group of other studies, however, suggest that cultural values are as important as environmental and economic values of our forests both for rural and urban communities, and increasingly include cultural values into regional forest ecosystem service valuation (MEA, 2005; Costanza et al., 1997; Wilson, 2008; Moore et al., 2011; Liu et al., 2010). People tend to place higher value on the cultural services of forests as their income increases.

This chapter estimates the economic values of cultural services provided by forests based on the perceptions Texans have on forests within the State. Putting a dollar value on these non-market ecosystem services is by no means the ultimate goal. Rather, it is the first step of acknowledging the importance of the ecosystem services provided by forests and incorporating this value into the decision making process. These estimates are likely below the current economic values of cultural services of Texas forests due to ever-increasing education efforts in the State, rising income in Texas, and potential interests from regions outside of Texas. This chapter assesses the cultural benefits associated with FIA-defined forests in rural and urban areas.

Aesthetic, Educational and Cultural Heritage Benefits of Forests

Forests are an important source of recreational enjoyment and aesthetic pleasure for many (MEA, 2005). They provide people opportunities to camp, hunt, take vacations, relax or simply enjoy nature. Many non-industrial, private forest landowners consider aesthetics as one of their major forest management goals (Gan and Miller, 2001). According to a recent survey by the Texas A&M Forest Service (Simpson and Li, 2010), enjoying scenery was one of the two highest-rated reasons for Texas private forest landowners to own forestland. Forests can be used for environmental education, biological research, wildlife habitation, and natural resource management (Loomis & Richardson, 2000). They can also be used for character building and as an inspirational source for artistic expression, clearing the mind for visualization and creative thinking (e.g., Morton, 1999; Herzog et al., 1997).

Passive Use Benefits of Forests

Passive use benefits reflect the utility gained from knowing forests are preserved, even if an individual does not visit or ever plan to visit the forest. Passive use benefits include option, bequest, and existence benefits. These benefits contribute to an individual's value for forest ecosystems. Option value reflects people's willingness to pay to conserve the option of his or her future use even though there is no present use made of the forests (Weisbrod, 1964). Bequest value is the satisfaction generated from preserving the resource for future generations (Krutilla, 1967). An individual might be willing to pay presently to ensure that the forest resources are available for his or her heirs and future generations. Existence value reflects an individual's willingness to pay for knowing that certain resources exist, even though he or she will most likely never use the resources (Randall and Stoll, 1983). For example, many people are willing to pay to protect certain endangered species from extinction, even though those animals may be located in hard-to-access areas.

Non-market Valuation

In the absence of markets for cultural benefits, non-market valuation methods are commonly used to estimate cultural values of forests. These valuation methods can be roughly classified into three groups: revealed preference, stated preference, and benefit transfer approaches. Revealed preference approaches exploit the relationship between certain observable individual behavior (e.g., visiting a park, buying a house, buying a hunting lease) and associated environmental attributes (e.g., forests, beach, water quality) to estimate the value of certain environmental services. The travel cost, hedonic pricing, and averting behavior methods are the most-well-known revealed preference methods. For example, people are shown to pay a premium for real estate surrounded by trees or adjacent to forests. Therefore, values attributed to forests can be estimated using a hedonic pricing method. However, the revealed preference methods rely on current and previous levels of the consumption of non-market goods, which may not be available for certain non-use values such as option value, bequest value and existence value.

Therefore, there is an increased interest in another group, the stated preference method, for non-market valuation. Stated preference methods estimate the value of non-market goods using individuals' stated behavior in a hypothetical setting. The group includes contingent valuation and stated choice modeling methods. Contingent valuation has been the most commonly used approach for estimating the value of environmental goods, such as aesthetic and non-use values (e.g., Walsh et al., 1984; Brookshire et al., 1983; Gan and Miller, 2001). There are several variations of the contingent valuation method depending on the elicitation techniques (e.g., bidding game, payment card, open-ended, and dichotomous choice approaches). Typically, in a contingent valuation survey, an individual is asked how much money he would be willing to pay to maintain the level of certain environmental goods. The economic value of the goods can be estimated based on an econometric analysis of the responses from a group of individuals.

In stated choice modeling, an individual is presented a hypothetical setting regarding a change in levels of certain non-market goods and asked to choose their preferred choice among several carefully-designed alternatives. Normally, a sequence of such choice sets is provided with trade-offs among various attributes associated with the good. Their preferences and values attached to various attributes are elicited based on their choices. Compared to contingent valuation, stated choice modeling is more flexible and able to reduce some potential biases and yield more information by providing more combinations of attributes. There has been an increasing number of studies using the stated choice modeling approach to estimate the non-use values of environmental resources, including wilderness area and forests (Adamowicz et al., 1998; Carvalho-Ribeiro and Lovett, 2011; Moore et al., 2011). For example, Adamowicz et al., (1998) estimated the passive use values of old-growth forests in Alberta using a contingent valuation approach and a choice modeling approach. Moore et al., (2011) estimated Georgia residents' willingness to pay for various aesthetic, cultural and non-use benefits provided by private forests using a stated choice modeling approach. For a critical review of stated preference methods, please see Kristrom and Laitila (2004).

Due to limitations on cost and time, sometimes it is neither feasible nor desirable to conduct a primary study for non-market goods valuation. As an alternative, the benefit transfer method, using previous estimates of values or benefit functions from a location in a similar context to the site of interest, is increasingly used in forestry related non-market valuation (Brander et al., 2006; Liu et al., 2010). Compared to other original valuation methods, the benefit transfer method is less costly and time consuming. However, the use of the benefit transfer method has been under scrutiny for applicability of the values or functions from one site to another site theoretically and empirically (Brookshire and Neil, 1992; Loomis et al., 2005).

Methods

Previous studies found that cultural values placed on forests vary greatly with personal and social-economic factors, cultural heritage, professional background, forest management intensity, type of recreational activities, and interactions with the forests of interest (Abello and Bernaldex, 1986; Tips and Vasdisara, 1986; Rogge et al., 2007; Winter 2005; Harshaw et al., 2006; Roovers et al., 2002; Carvalho-Ribeiro and Lovett, 2011). Therefore, the benefit transfer approach that works well for other non-market valuation of ecosystem services may not be suited for estimating the value of cultural services of Texas forests. To better capture the cultural values attached to Texas forests, an original survey was conducted. Survey results provided information on the preferences and opinions Texans have about Texas forests, and were used to estimate the economic value of cultural services using the stated choice modeling approach. Detailed discussion of the stated choice approach used in this analysis is in Appendix A.

Survey Design and Implementation

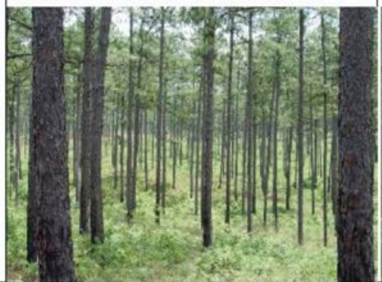
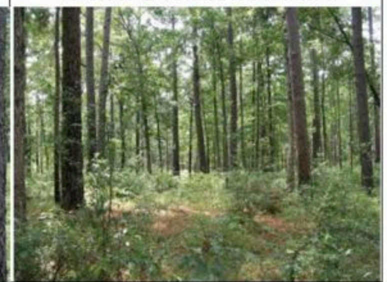
The survey (provided in Appendix B) was designed by Texas A&M Forest Service and Texas A&M AgriLife Extension Service. There are four major sections in the survey instrument. In the first section, survey respondents were asked questions about their general perceptions of and experiences with Texas forests. The second section focused on their opinions on ecosystem services and goods provided by the forests and concerns on forestland management. The third section included a set of stated choice questions for cultural benefit valuation. The last section concluded with questions on social-economic and demographic characteristics of respondents.

In the third section, respondents were first asked to rank sample photos of the six major forest types based on visual attractiveness. The photos were selected from a digital image database maintained by Texas A&M Forest Service. Other factors (e.g., season, background colors, sky color, roads), wherever possible, were controlled to show only variations in forest type. The respondents were then asked to vote in a hypothetical ballot initiative that would cause changes in the forests in Texas. Each respondent was presented four choice sets. For each choice set, respondents were given two different alternatives with changes in attribute levels associated with Texas forests and the *status quo* (no change). Five factors were identified as attributes potentially affecting respondents' valuation of cultural benefits provided by forests: management priority, forest type, forest area, land ownership, and additional annual household expenses due to price increase in wood products, utilities or other costs. Table 44 presents the five attributes and associated variations in their levels.

Table 44. Attributes in the Texas forests cultural values analysis.

Attributes	Level
Management priority	Educational, biodiversity, recreational, none
Forest type	Natural pine, pine plantation, mixed, hardwood, woodland, urban forest
Ownership	Public, private
Changes in forest area	1% increase, 1% decrease, no change (*status quo*)
Additional increase in annual household expenditure	\$5, \$10, \$25, \$50, \$75, \$100

Using the five attributes with four, six, two, three, and six levels for the various attributes, the full factorial set of 864 combinations was generated. While it might be tempting to use the full factorial, it is not efficient and practical. Out of the full 864 factorial, 80 combinations were selected as the final feasible choice alternatives using the OPTEX procedure of SAS®. Since each questionnaire has four choice sets, there are a total of 10 versions of the survey questionnaire with different choice sets. See Figure 11 for an example of a choice set. Photos representing each forest type were presented in the choice set as a visual aid and means to incorporate aesthetic value into choice.

D-4 Attributes	Option A	Option B
Management Priority	NONE	BIODIVERSITY
Proposed Changes	1% increase in Natural Pine forested area that looks like... 	1% increase in Pine/Hardwood forested area that looks like... 
Ownership	Private	Public
Additional Annual Costs	$5	$10

D4. I vote for... ☐ **Status-quo** ☐ **Option A** ☐ **Option B**

Figure 11. An example of choice set used for valuation.

Earlier versions of the questionnaires were piloted to a focus group. After incorporating changes, the survey questionnaires were distributed to the general public in two ways: 1) by mail with postage-paid return envelope, and 2) by email with a link to the web based survey hosted by SurveyMonkey®. The mail survey was sent by Readex Research, on behalf of Texas A&M Forest Service and Texas A&M AgriLife Extension Service. Mailing addresses of 3,000 randomly selected Texas residents were obtained from USAData, Inc. Each version of the survey was sent to 300 respondents in May 2012. USAData sent an email with a description of the project and a link to the web-based survey to 150,000 randomly selected Texas residents during June and July 2012. To increase the response rate, respondents were entered into a drawing for a chance to win one of two $1,000 gift cards. Additionally, the web survey was also sent to approximately 1,000 forestry-related individuals in Texas. The forestry-related individuals include forest landowners, loggers, private consulting foresters, forest industry professionals, and other forestry professionals.

Sample Characteristics

A total of 683 questionnaires were collected. Of the 552 web-based responses, 161 were identified as being from the forest sector. The remaining 391 web-based and the 131 mailed questionnaire responses represented the general public in Texas. While this represents a relatively low overall response rate, the number of questionnaires received was considered adequate for this analysis. Table 45 presents the social-economic profile of the survey respondents. Seventy-three percent of respondents were from urban/suburban areas or small towns (or 27% were from rural area). According to the 2010 U.S. census, 15% of Texas' total population is rural, indicating this sample included a higher percentage of the rural population. Fifty-eight percent of the respondents were male. Slightly more than half of the respondents were between 46 and 65, suggesting this age group was more likely to return the survey and presumably more interested in the topic. Interestingly, the distribution patterns among age groups were similar for both the mail and web-based surveys. Sixty percent of respondents hold a bachelor degree or higher, compared to 25 percent for the State population over 25 years of age. Sixty-four percent of respondents were white, compared to 45 percent of white population in Texas. Twenty-five percent of the respondents selected none of the listed ethnicities. Seventy-one percent of respondents reported that they are registered voters, compared to 53 percent for the State voting-age population (U.S. Census Bureau, 2010). Twelve percent of respondents claimed that they are members of environmental groups. Twenty-three percent of respondents claimed that they currently owned forestland in Texas when taking the survey.

Table 45. Social-demographic characteristics of survey respondents.

Category	Label	Response (%)
Current residence	Urban	20
	Suburban	32
	Small town	22
	Rural	27
Gender	Female	42
	Male	58
Age	<21	1
	22 – 45	23
	46 – 65	54
	66 – 75	16
	75+	7
	Average age = 53.6 years	
Highest education	High school graduate or less	13
	Associate degrees	27
	Bachelor	36
	Advanced degrees	24
Ethnicity	White	64
	Hispanic	5
	Black	3
	Native American	2
	Asian	1
	Other	25
Registered voter	Yes	71
	No	29
Environmental organization member	Yes	12
	No	88
Forestland ownership	Yes	23
	No	77

For respondents who claimed that they currently own forestland in Texas, additional questions regarding the acquisition, ownership and management objectives of their forestland were asked. Table 46 shows the information. Fifty-nine percent of respondents reported that their forestland was acquired by purchase, while twenty-one percent reported acquisition by inheritance or gift. Another twenty percent indicated acquisition by both ways. In terms of size of forestland ownership, twenty-three percent of the respondents reported that they own less than 10 acres. Thirty-eight percent of respondents claimed that they own less than 50 acres of forestland, compared to 84% of Texas family forestland owners having land less than 50 acres in 2006 (Butler et al., 2012).

Table 46. Forestland ownership and acquisition information for respondents owning forestland in Texas.

Statements	Label	Response (%)
How did you acquire the forestland?	Purchase	59
	Inheritance / gift	21
	Both	20
How many acres do you currently own?	Less than 10 acres	23
	11 – 20 acres	6
	21 – 50 acres	9
	51 – 100 acres	16
	101 – 200 acres	14
	201 – 500 acres	14
	501 – 1,000 acres	8
	More than 1,000 acres	10

Respondents were asked about the importance of several well-known reasons for owning forestland on a scale of 1 (not important) to 5 (most important) (Figure 12). Enjoying scenery/protecting nature was the top-rated reason for owning forestland, rated at 4.0 on the 5.0 point scale. This indicated the importance of aesthetic values and possible cultural values of forestland to landowners. Land investment was also quoted as an important reason for forestland ownership, rated at 3.6. Being part of primary or vacation home and generating income from timber production or hunting were shown somewhat important with a score of 3.4 and 3.0, respectively. Interestingly, this result is consistent with a forestland owner survey on ecosystem services with a larger sample size (Simpson and Li, 2010).

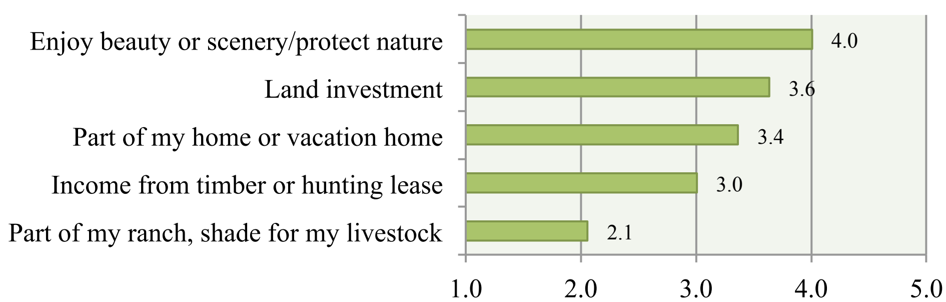


Figure 12. Survey participants' responses to question: "How important are the following reasons to you for owning forestland?" (1 = not important; 5 = very important)

Results

Respondents' self-evaluated knowledge of forest ecosystem services in Texas

Seventy-five percent of respondents indicated they have at least some level of understanding of forest ecosystem services in Texas (Figure 13).

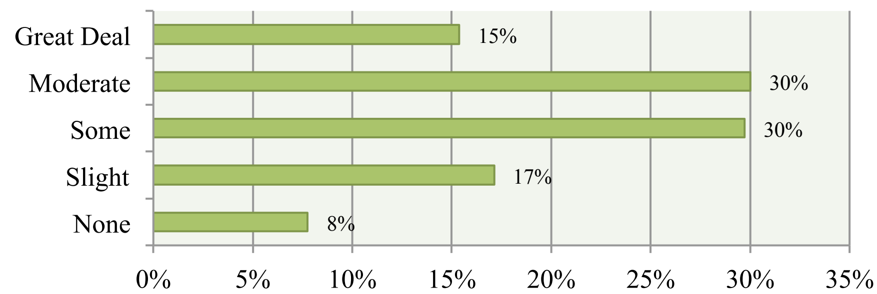


Figure 13. Percentage of the survey respondents' self-evaluated ranking of their knowledge of forest ecosystems in Texas by knowledge level.

Respondents' recreational experience with Texas forests

Respondents were asked about their recreational experience with a forested area in Texas by activity on a scale of 0 (never) to 4 (very often). Figure 14 shows the average usage of forests by respondents. Enjoying scenic views of forests while driving was the most frequent recreational usage of forests (average 3.1 out of 4.0). Having a picnic, bird/wildlife watching, photographing, fishing and swimming in water within forests were the next most frequent uses (averages ranging from 2.7 to 2.9). Forests were occasionally used for hiking, biking, camping, and hunting (averages ranging from 2.2 to 2.5).

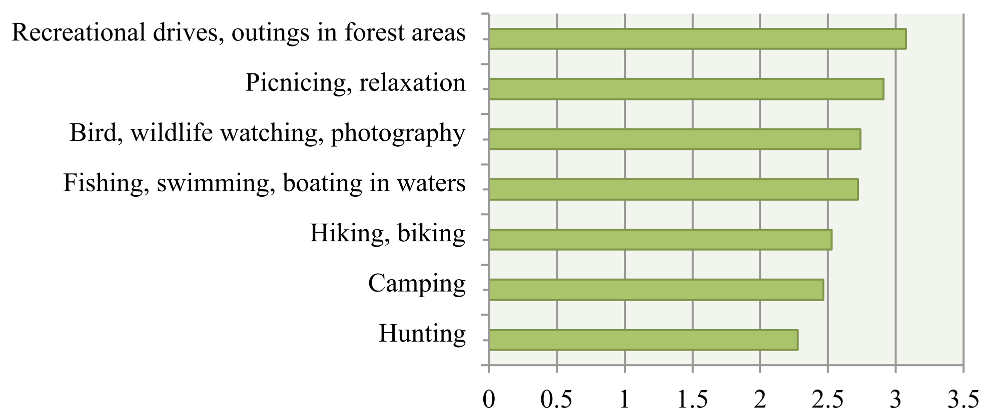


Figure 14. The averaged response to the survey question: How often have you participated activities in forested area in recent years? (0 = Never; 4 = Very Often).

Option and bequest use of forests

To elicit the option and bequest uses of forests, respondents were asked about their potential uses of forests and anticipation of forest uses by their future generation. A great majority of respondents (91%) indicated that they intend to visit the forests, showing option use of the forests (Figure 15). Nineteen percent of the respondents anticipated that their descendants might visit the forests, suggesting bequest use of the forests to some Texans.

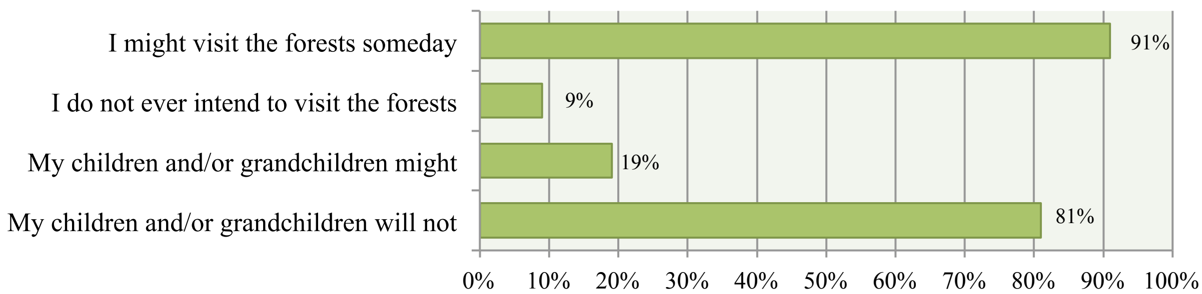


Figure 15. Percent respondents' reply to the bequest use question: Do you or your family ever intend to visit the forests?

Existence use of forests

To elicit existence benefits of forests, respondents were asked to indicate their level of agreement with the statement of "*Whether or not I visit forests, just knowing that they are healthy and well-managed is important to me.*" Interestingly, an overwhelming ninety-one percent of the respondents strongly agreed or agreed that it is important to them to know that Texas forests are healthy and well-managed whether they visit the forests or not (Figure 16). This indicated that Texans derive satisfaction from the existence of healthy and well-managed forests.

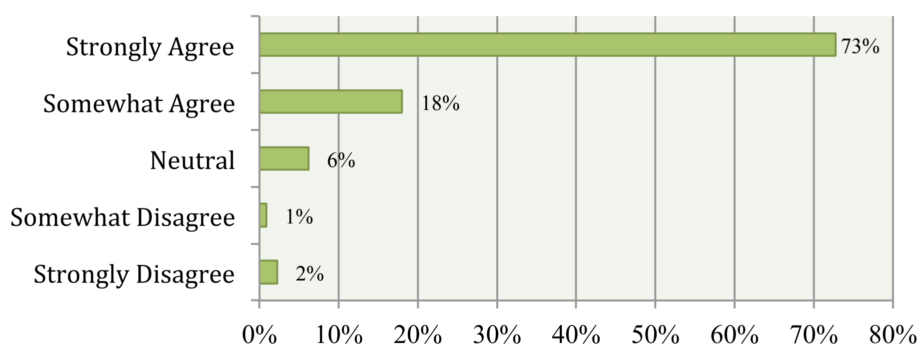


Figure 16. Response rate to the survey question: Whether or not I visit forests, just knowing that they are healthy and well-managed is important to me?

Changes in Texas forestland

Sixty-one percent of respondents feel the forestland in the region they're most familiar with changed over the last decade or more (Figure 17). Of them, the great majority felt the forest area decreased while a small percentage felt the forest area increased. Around one third of the respondents felt the forest area in their region remained about the same over the last decade.

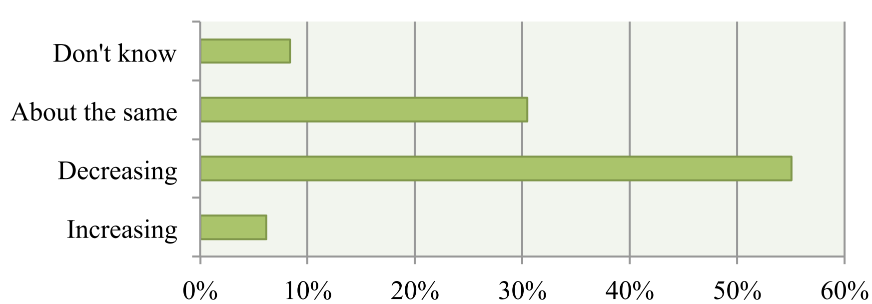


Figure 17. Results to the survey question: From what you have observed over the last decade or more, do you feel that the amount of forested land in the region for which you are most familiar is...

Benefits provided by forests

Most respondents acknowledged that they received benefits from various forests in Texas. Figure 18 shows the percentage of respondents receiving various benefits by forest type. For each forest type, more than fifty percent of respondents acknowledged the environmental benefits (air, water, carbon storage, wildlife habitats, and scenic view). Public rural forests are acknowledged to provide recreational opportunities, improve air and water quality, regulate climate, and provide scenic beauty. Private rural forests are acknowledged to provide wood, fiber and other traditional forest products in addition to environmental benefits while recreational use (38%) is lower than other forest types. Urban forests provide scenic beauty and other environmental benefits. Forty-seven percent of the respondents claimed that they received recreational benefits from forests in *Central/West Texas*, the second highest just behind public rural forests.

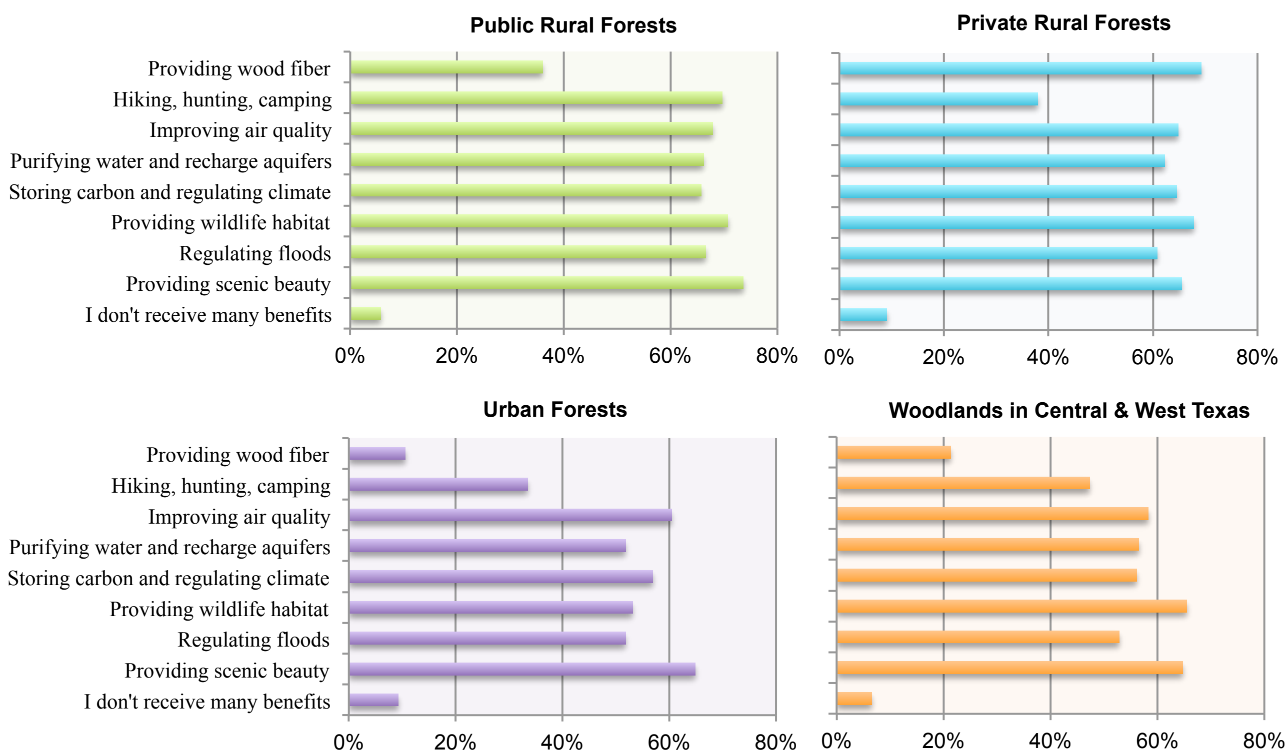


Figure 18. Perceptions of benefits provided by Texas forests.

Additionally, respondents were asked to choose one of the reasons above as the sole management objective for each type of forest. Providing recreational opportunities received the highest vote for public rural forests. Providing fiber and other forest products surpassed all others as the major desirable management objective for private rural forests. Providing scenic beauty and opportunities for recreation were equally voted as the major management objectives for urban forests. Providing wildlife habitat and maximizing water quality/quantity were voted as the top management objective for forests in *Central/West Texas*. Ninety-one percent of the respondents strongly agreed or agreed that improved forest health and resilience benefit all citizens.

Negative impacts from forests

Respondents were also asked to check negative influences from forests. Figure 19 shows the major complaints about forests. Most of the concerns were from urban forests.

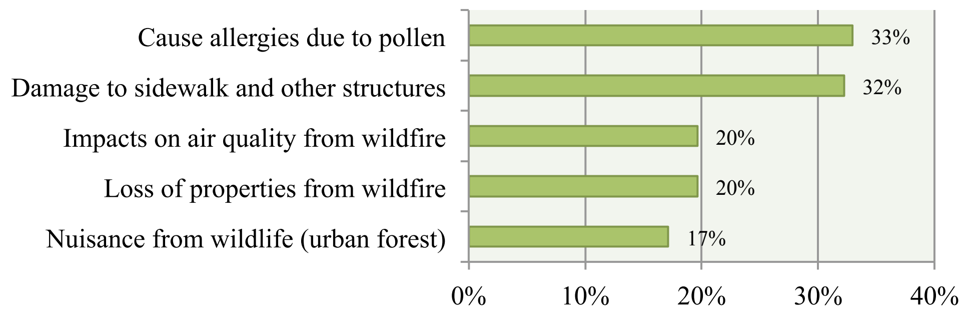


Figure 19. Results of the survey question: Which of the following negative aspects, if any, do you associate with forests?

Compensation to landowners for environmental benefits

Sixty-percent of the respondents strongly agreed or agreed that forest landowners should be compensated for economic loss due to harvest restrictions for environmental benefits (Figure 20). Twenty-two percent of the respondents disagreed with compensating landowners for the economic loss with about 17 percent being neutral.

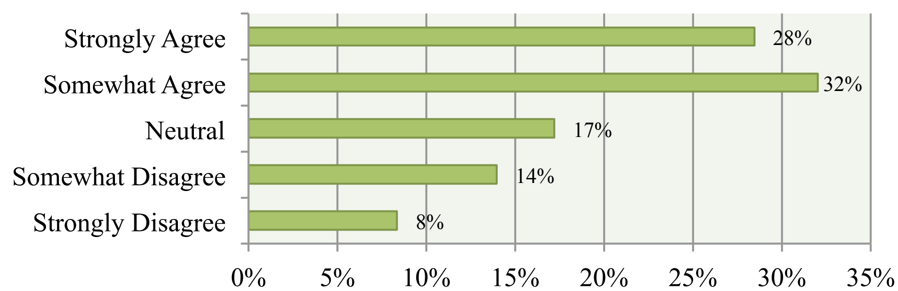


Figure 20. Responses to the survey question: Landowners should be paid for any economic loss if they are prevented, by law or policy, from cutting trees.

Land Management Considerations

Respondents were also asked about their opinions on forest management in Texas. Not surprisingly, there is a sharp contrast between the general public and the forestry community over several issues on land management. Seventy-six percent of respondents from the forestry community trusted forest owners in Texas to maintain healthy forests in the long term while only 43% of general public agreed (Figure 21). When they were asked about the role of government in forestland management, the general public was split among various level of agreement while an overwhelming percent (85%) of respondents from the forestry community disagreed on government oversight (Figure 22). Note that around two-thirds of the forestry-related respondents own forestland. This indicated that forest owners have strong confidence in their forest management and prefer to manage their land with less government oversight and intervention.

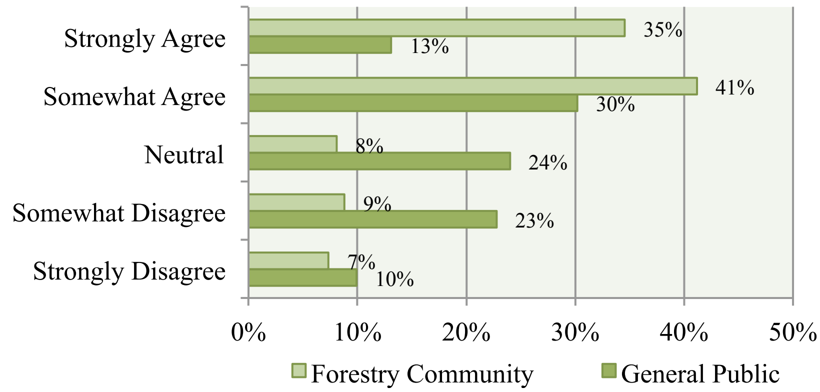


Figure 21. Responses to the question: I trust Texas forest owners to maintain healthy forests in the long term.

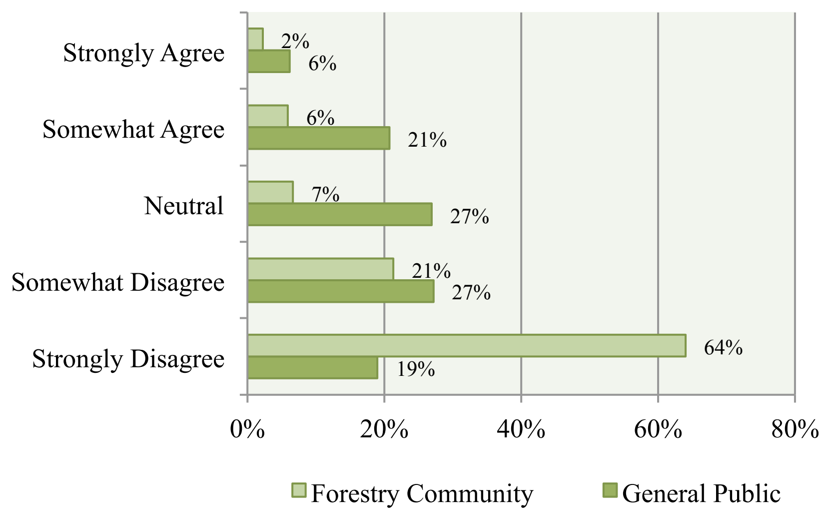


Figure 22. Percentage of responses to the survey question: Forests should be managed by government oversight.

Cultural Values for Forests in Texas

Data from the choice questions were analyzed using a logistic regression model. Table 47 presents the estimated annual willingness to pay by an average household for a 1,000-acre increase in the area of Texas forest by forest type. An average household in Texas is willing to pay between $0.54/year to $2.22/year for a 1,000-acre increase in forest area depending on the type of forest. Public urban forests were the highest valued forest type ($2.22/year/thousand acres), while woodland forests in *Central/West Texas* were the lowest valued forest type ($0.54/year/thousand acres).

Table 47. Estimated marginal annual willingness to pay (WTP) for a 1,000-acre increase in forests in Texas, by forest type.

Forest Type	Annual WTP per Household ($/yr/ac)
Private rural forestland (pine, mixed, hardwood)	$0.93
Public rural forestland (pine, mixed, hardwood)	$1.29
Woodland outside of East Texas	$0.54
Private urban forestland	$1.86
Public urban forestland	$2.22

The impacts of several other socioeconomic factors on Texans' marginal WTP for forests in Texas were also tested. Factors strongly associated with a higher marginal WTP for forests include owning forestland in Texas, living in an urban or suburban area, having children, and being a member of an environmental organization or advocacy group. On average, the annual WTP per thousand acre forest increase for a forest owner is $0.09 higher than a non-forest owner. Texans would pay a premium for forests managed for educational purposes. There were no significant differences in WTP for Texas forests between gender, education level, race, being a forestry professional or not, and political affiliation.

An aggregate per acre cultural value of forests was estimated by multiplying the per acre household's annual WTP by the number of households (Table 48). Previous studies suggested that people are inclined to attach higher WTP for resources which may have direct impacts or consequences on them (e.g., Pate and Loomis, 1997; Concu, 2007; Kozak et al., 2010). Only the population within the ecoregion in which the forests were located were considered to estimate the per acre cultural values of forests in Texas. Since people living outside of the ecoregion most likely value these forests, the true cultural value could be much higher than the estimates listed in Table 48.

Table 46 presents estimates of cultural values of the 581.4 thousand acres of FIA-defined forests that reside within urban areas in Texas by ecoregion. Although urban forests totaled 1.2 million acres, the survey was not designed to assess the cultural values of the remaining 649.3 thousand acres of street, residential, and park trees. Cultural values are likely significantly different for street, residential, and park trees and as such, are beyond the scope of this study. Furthermore, since the ownership patterns of forestland in these areas were not available, only the aggregates are presented. Per acre values of private urban forests in each ecoregion were used as a conservative approximation to estimate the total cultural value.

The total cultural value of Texas forests to the residents of Texas is $60.4 billion/year, including $59.2 billion/year for 61.8 million acres of rural forests and $1.2 billion/year for 581.4 thousand acres of FIA defined forests in urban areas of the State. Since only the population where the forests are located was considered, these estimates are very conservative. Also, because cultural values make up 65% of the total ecosystem services value of forests in Texas, varying the estimated value placed on cultural services by Texans has a significant impact to the assessed value of forest ecosystem services. A 25% reduction in the WTP per average household for a 1,000-acre increase in the area of Texas forest causes a 16.2 percent decrease (from $93.1 billion/year to $78.0 billion/year) in the total ecosystem service value. Likewise, a 25% increase in WTP raises the value to $108.2 billion/year (16.2% increase).

Table 48. Estimated cultural values for rural forests in Texas, by ecoregion and forest type. Total forest acres in rural areas is 61.8 million acres. Economic values may reflect slight discrepancies due to rounding.

Ecoregion/Forest Type	Value ($/ac/yr)	Area (thousand acres)	Total Value (million $/yr)
Pine Woodlands			
Private rural forestland	857.82	8,828.69	7,573.46
Public rural forestland	1,189.88	972.10	1,156.68
Woodland	498.09	35.12	17.49
Subtotal	[a]**889.35**	***9,835.90***	***8,747.63***
Coastal Woodlands			
Private rural forestland	1,708.80	1,216.09	2,078.05
Public rural forestland	2,370.26	83.68	198.35
Woodland	992.20	595.01	590.37
Subtotal	[a]**1,512.97**	***1,894.79***	***2,866.78***
Post Oak			
Private rural forestland	$2,361.03	4,514.53	10,658.94
Public rural forestland	$3,274.98	325.50	1,065.99
Woodland	$1,370.92	868.06	1,190.04
Subtotal	[a]**2,262.58**	***5,708.08***	***12,914.97***
Hackberry-Oak			
Private rural forestland	1,199.91	4,394.25	5,272.69
Public rural forestland	1,664.39	222.90	370.99
Woodland	696.72	10,606.82	7,389.99
Subtotal	[a]**845.15**	***15,223.97***	***13,033.67***
Mesquite-Juniper			
Private rural forestland	1,194.51	7,732.33	9,236.37
Public rural forestland	1,656.91	139.67	231.42
Woodland	693.59	16,052.33	11,133.71
Subtotal	[a]**861.11**	***23,924.33***	***20,601.51***
High Plains			
Private rural forestland	373.57	277.29	103.59
Public rural forestland	518.17	16.33	8.46
Woodland	216.91	2,046.39	443.88
Subtotal	[a]**237.58**	***2,340.02***	***555.93***
Mountain			
Private rural forestland	245.82	267.70	65.81
Public rural forestland	340.98	45.03	15.35
Woodland	142.73	2,603.06	371.54
Subtotal	[a]**155.26**	***2,915.79***	***452.70***
Total		**61,842.87**	**59,173.19**

[a]Weighted average for each ecoregion.

Table 49. Estimated cultural values for FIA-defined forests in urban areas of Texas by ecoregion.

Ecoregion/Forest Type	Value ($/ac/yr)	[a]Area (thousand acres)	[b]Total Value (million $/yr)
Pine Woodlands			
Private urban forestland	$946.40	-	
Public urban forestland	$1,129.57	-	
Subtotal		**149.06**	**141.07**
Coastal Woodlands			
Private urban forestland	$2,261.00	-	
Public urban forestland	$2,698.61	-	
Subtotal		**102.22**	**231.11**
Post Oak			
Private urban forestland	$3,616.72	-	
Public urban forestland	$4,316.73	-	
Subtotal		**150.22**	**543.28**
Hackberry-Oak			
Private urban forestland	$1,672.51	-	
Public urban forestland	$1,996.22	-	
Subtotal		**69.69**	**116.56**
Mesquite-Juniper			
Private urban forestland	$1,553.89	-	
Public urban forestland	$1,854.64	-	
Subtotal		**109.38**	**169.96**
High Plains			
Private urban forestland	$595.52	-	
Public urban forestland	$710.78	-	
Subtotal		**0.83**	**0.49**
Mountain			
Private urban forestland	$478.24	-	
Public urban forestland	$570.81	-	
Subtotal		**0.04**	**0.02**
Total		**581.43**	**1,202.50**

[a]Forestland area by ownership is not available.
[b]Per acre cultural value of private urban forest is used as a conservative approximation.

Summation of Forest Services in Texas

Texas forests provide numerous ecosystem services that are essential to the survival and well-being of all citizens in the State. These forests cover 61.8 million acres in rural areas and 581.4 thousand acres in urban areas. In addition to the previously assessed ecosystem services, air quality regulation was also evaluated for forests in urban areas using the Urban Forest Effects model (UFORE) and estimated values (Nowak and Greenfield, 2010) shown in Table 50.

Table 50. Estimated air quality regulation value of forests in urban areas of Texas.

Pollutant	Service Rate (t/ac/yr)	Service Rate (t/yr)	Service Value ($/ac/yr)	**Total Value for (million $/yr)**
CO	0.0011	652.88	1.78	**1.03**
NO_2	0.0045	2,641.75	48.41	**28.15**
O_3	0.0176	10,206.56	187.05	**108.76**
SO_2	0.0025	1,443.23	6.47	**3.76**
PM_{10}	0.0117	6,829.72	83.57	**48.59**
Total	**0.0374**	**21,774.15**	**327.28**	**190.29**

The regulating (biodiversity, carbon, watershed, and air quality) and cultural services provided by the State's 61.8 million acres of rural forests and 581.4 thousand acres of forestland in urban areas provide benefits worth an estimated $92.9 billion annually (Table 51). At 65%, cultural service, by far, made the greatest economic contribution to the total forest ecosystem service value in Texas (Figure 23). The values for ecosystem services provided by rural and urban forests in the *East Texas* region and the *Central/West Texas* region are provided in Tables 52 and 53. Rural and urban forests located in the *East Texas* region provide more than $26.2 billion ($25.4 billion in rural areas and $0.8 billion in urban areas) worth of ecosystem services annually while the rural and urban forests located in the *Central/West Texas* region provided more than $68.3 billion ($66.9 billion in rural areas and $1.5 billion in urban areas) of ecosystem services annually.

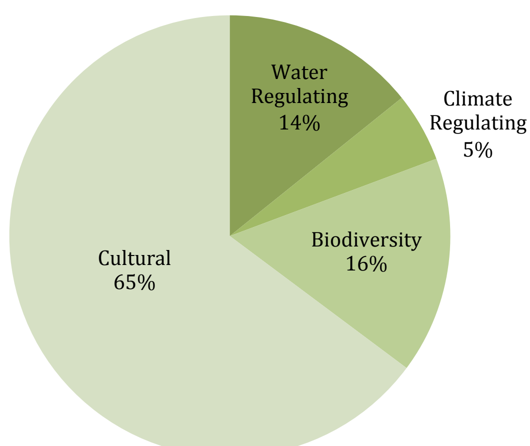


Figure 23. The percent contribution by each assessed service to the total ecosystem service value of forest in Texas.

Table 51. Value of ecosystem services provided by Texas forests in rural and urban areas by type of service. Values may reflect slight discrepancies due to rounding.

	Rural (61.8 million acres)		Urban (581.4 thousand acres)		
Service	Value ($/ac/yr)	Total Value (million $/yr)	Value ($/ac/yr)	Total Value (million $/yr)	Rural + Urban (million $/yr)
Watershed					
Water capture	7.74	478.52	19.12	11.12	489.64
Water filtration	66.31	4,100.72	179.08	104.12	4,204.84
Water regulation	128.00	7,915.92	530.03	609.37	8,568.25
subtotal	**202.05**	**12,495.17**	**728.22**	**724.60**	**13,262.74**
Climate					
Carbon stocks	49.79	3,079.28	30.55	17.26	3,097.04
Carbon accumulation	18.62	1,151.57	11.30	6.39	1,158.14
Air quality			327.28	190.29	190.29
subtotal	**68.41**	**4,230.85**	**369.13**	**213.94**	**4,445.47**
Biodiversity					
Base	232.00	14,347.55	232.00	134.89	14,482.44
Hotspots	51.75	324.49	51.75	1.58	326.07
subtotal	**237.25**	**14,672.04**	**234.72**	**136.47**	**14,808.51**
Cultural					
Private land	245 - 2,361	34,988.91	478 - 3616	1,202.50	36,191.41
Public land	340 - 3,274	3,047.25	570 - 4316	-	3,047.25
Woodland	142 - 1,370	21,137.03	-	-	21,137.03
subtotal	**956.83**	**59,173.19**	**2,068.18**	**1,202.50**	**60,375.69**
Total	**1,464.54**	**90,571.24**	**3,918.27**	**2,277.52**	**92,849.44**

Table 52. Value of ecosystem services provided by forest in rural and urban areas of *East Texas* region by service. Values may reflect slight discrepancies due to rounding.

	Rural (11.8 million acres)		Urban (227.4 thousand acres)		
Service	Value ($/ac/yr)	Total Value (million $/yr)	Value ($/ac/yr)	Total Value (million $/yr)	Rural + Urban (million $/yr)
Watershed					
Water capture	30.12	356.76	30.09	6.85	363.61
Water filtration	206.00	2,440.34	251.55	57.22	2,497.55
Water regulation	447.33	5,299.17	1,271.69	289.26	5,588.43
subtotal	**683.44**	**8,096.27**	**1,553.34**	**353.32**	**8,449.59**
Climate					
Carbon stocks	66.93	792.91	30.33	6.90	799.81
Carbon accumulation	22.19	262.90	18.26	4.15	267.06
Air quality			327.28	74.44	74.44
subtotal	**89.13**	**1,055.81**	**375.87**	**85.50**	**1,141.31**
Biodiversity					
Base	232.00	2,748.35	232.00	52.77	2,801.12
Hotspots	51.75	50.10	51.75	0.34	50.45
subtotal	**236.23**	**2,798.46**	**233.51**	**53.11**	**2,851.57**
Cultural					
Private land	498 -2,361	12,012.27	946 – 3,616	336.01	12,348.29
Public land	1,189 – 3,274	1,459.46	1,129 -4,316		1,459.46
subtotal	**1,137.20**	**13,471.73**	**1,477.24**	**336.01**	**13,807.74**
Total	**2,146.00**	**25,422.27**	**3,639.96**	**827.94**	**26,250.22**

Table 53. Value of ecosystem services provided by forests in rural and urban areas of *Central/West Texas* region by service. Values may reflect slight discrepancies due to rounding.

	Rural (50.0 million acres)		Urban (353.9 thousand acres)		
Service	Value ($/ac/yr)	Total Value (million $/yr)	Value ($/ac/yr)	Total Value (million $/yr)	Rural + Urban (million $/yr)
Watershed					
Water capture	2.44	121.76	12.07	4.27	126.03
Water filtration	82.02	4,100.72	132.50	46.90	4,147.63
Water regulation	52.34	2,616.75	1,025.72	363.07	2,979.82
subtotal	**136.79**	**6,839.23**	**1,170.30**	**414.25**	**7,253.48**
Climate					
Carbon stocks	45.68	2,283.93	25.63	9.07	2,293.00
Carbon accumulation	17.76	887.90	9.96	3.53	891.42
Air quality			327.28	115.85	115.85
subtotal	**63.44**	**3,171.82**	**362.87**	**128.45**	**3,300.27**
Biodiversity					
Base	232.00	11,599.19	232.00	82.12	11,681.31
Hotspots	51.75	274.39	51.75	1.24	275.63
subtotal	**237.49**	**11,873.58**	**235.50**	**83.36**	**11,956.94**
Cultural					
Private land	142 – 2,361	25,960.76	478 – 3,616	866.49	26,827.25
Public land	340 – 3,274	19,026.38	570 – 4,316		19,026.38
subtotal	**899.81**	**44,987.14**	**2,447.91**	**866.49**	**45,853.63**
Grand Total	**1,337.53**	**66,871.78**	**4,216.58**	**1,492.54**	**68,364.32**

A sensitivity analysis was conducted to evaluate the impact of several economic assumptions used in this assessment. Estimates representing the spectrum of values reported in the literature were analyzed to determine their effect on each respective service, as well as the total value of all ecosystem services assessed in this report. The value and percent change in values, as compared to the estimates used in this assessment, for each service and the total assessed ecosystem service values are reported in Table 54 and illustrated in Figures 24 – 26.

Watershed: Forest watershed service values used in this assessment were compared to estimates reported in four other state level ecosystem service valuation projects: Florida (Escobedo, 2010), Georgia (Moore, 2009), Maine (Troy, 2012), and New Jersey (Costanza, 2006). Estimates (adjusted to 2011 USD) were evaluated across all watershed functions and land cover types to determine the low, median, and high values. These varying estimates were then applied to the representative area of Texas forestlands to assess their impact on the total watershed service value (Table 54). For simplicity, the fluctuating estimates were converted to a total, weighted, per forested acre value ($96.5/acre, $468.1/acre, and $1,139.0/acre) and compared to the value used in this assessment ($211.8/acre). As expected, the watershed regulating service is sensitive to the varying estimates, resulting in a 54.4% decrease, 121.0% increase, and a 437.8% increase, respectively in the watershed service value (Figure 24). Similarly, while not as dramatic, the total assessed ecosystem service values changed substantially when applying the fluctuating estimates, resulting in a 7.8% decrease, 17.1% increase, and 62.1% increase, respectively, in the total assessed ecosystem service value (Figure 25).

Climate: As discussed in Appendix A, value of sequestered carbon range varies greatly from $5.5/tC – 322.4/tC (all adjusted to 2011 dollars). To make meaningful inference to the sensitivity of carbon values to the overall Climate Regulating ecosystem services value, a less-variable range such as that suggested by the U.S. government's Interagency Working Group on Social Cost of Carbon (2010) was used. This group estimated the social cost of carbon within a range of $5.4 - $70.3/tC (adjusted to 2011 USD). As such, the change in the total value of the Climate Regulating ecosystem service was assessed by fluctuating the economic value of carbon from $22/tC to $5, $45, and $70/tC (Table 54). The change in the value of carbon had a substantial impact to the value of the single ecosystem service, climate regulation, by a 77.3% decrease, 104.5% increase, and a 218.2% increase, respectively (Figure 24). The variation in the value of sequestered carbon had relatively small impact, however, to the total value across all ecosystem services -- 3.6% decrease to 10.1% increase in total service value with $5 to $70/tC, respectively (Figure 25).

Table 54. The economic impact (dollar value and percent change) made to each ecosystem service as a result of varying the per acre service value as reported in similar studies.

	Reported Value		Low Value		Median Value		High Value	
Ecosystem Service	Value (million $/year)	Change %	Value (million $/year)	Change %	Value (million $/year)	Change %	Value (million $/year)	Change %
Watershed	$211.77/acre		$96.50/acre		$468.06/acre		$1,138.99/acre	
Within Service	13,219.77	-	6,024.07	(54.43)	29,218.35	121.02	71,100.89	437.84
Across Services	92,864.89	-	85,934.38	(7.77)	109,128.66	17.12	151,011.20	62.08
Climate	$22/tC		$5/tC		$45/tC		$70/tC	
Within Service	4,270.63	-	970.60	(77.27)	8,735.37	104.55	13,588.36	218.18
Across Services	92,864.89	-	89,781.24	(3.59)	97,641.80	4.85	102,554.66	10.13
Biodiversity	$232/acre		$130/acre		$430/acre		$630/acre	
Within Service	14,808.51	-	8,441.23	(43.00)	27,168.52	83.47	39,653.38	167.77
Across Services	92,864.89	-	86,754.70	(6.84)	105,481.99	13.27	117,966.85	26.68
Cultural			75% of Reported Values		125% of Reported Values		150% of Reported Values	
Within Service	60,375.69	-	34,390.22	(25.00)	57,317.04	25.00	68,780.45	50.00
Across Services	92,864.89	-	78,028.06	(16.21)	108,215.90	16.21	123,309.83	32.42

Biodiversity: For this report, simplified methods and values obtained from the literature were used to estimate the total biodiversity value of Texas forests. Yet, an ecosystem valuation assessment of this magnitude benefits by analyzing the impact made to the total ecosystem services value of Texas forest from varying the assumed biodiversity values. Listed in Table 54 are economic values of the biodiversity base value when adjusted to $130, $430, and $650/acre/year while holding the value for the top 10% ecologically important acres consistent at $51.8/acre/year. Obviously, the biodiversity service value is sensitive to the fluctuation of these values (Figure 24), but the total economic value across all ecosystem services is also relatively sensitive to assumed values. Lowering the assumed base value from $232 to $130/acre/year reduces the overall service value by 6.8 percent. Conversely, increasing the assumed base value from $232 to $430/acre/year, essentially doubling the value base service value, increased the overall service value by 13.7 percent.

Cultural: Because cultural values are 65% of the total ecosystem services value of forests in Texas, varying the estimated value placed on cultural services by Texans has a significant impact to the assessed value of forest ecosystem services. As shown in Table 54 and Figure 25, a 25% reduction in the WTP per average household for a 1,000-acre increase in the area of Texas forest causes a 16.2 percent decrease (from \$93.1 billion/year to \$78.0 billion/year) in the total ecosystem service value. Likewise, a 25% increase in WTP raises the value to \$108.2 billion/year (16.2% increase).

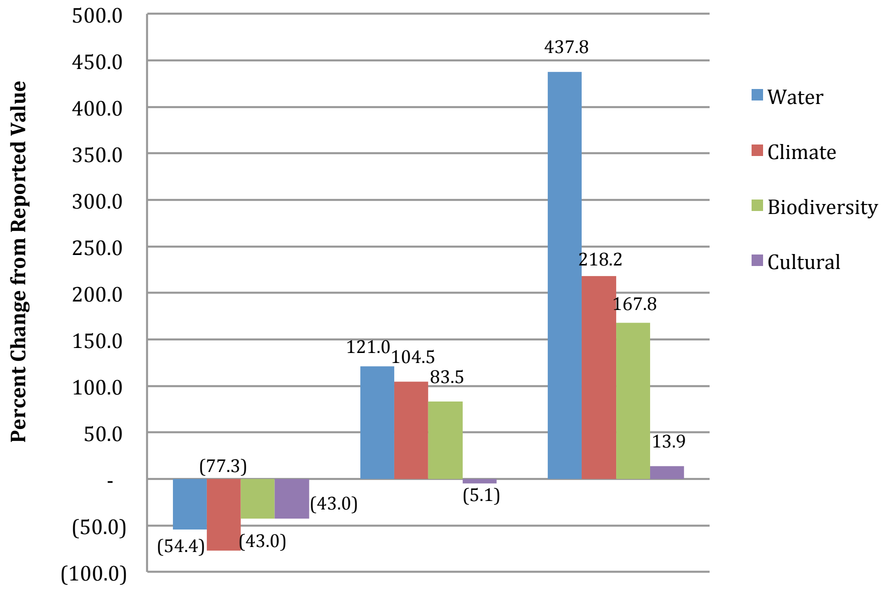


Figure 24. The economic impact (percent change) made to each individual ecosystem service by varying the service values per acre as reported by similar studies.

All Assessed Ecosystem Services: Changing the individual service values to the lowest estimates reported in the literature would reduce the overall assessed ecosystem service value provided by Texas forests by \$32.1 billion/year (34.5%). Likewise, changing all values to the median and high ranges reported in the literature increases the total ecosystem service value by 53.0% (\$142.5 billion/year) and 136.0% (\$219.9 billion per year), respectively (Figure 27).

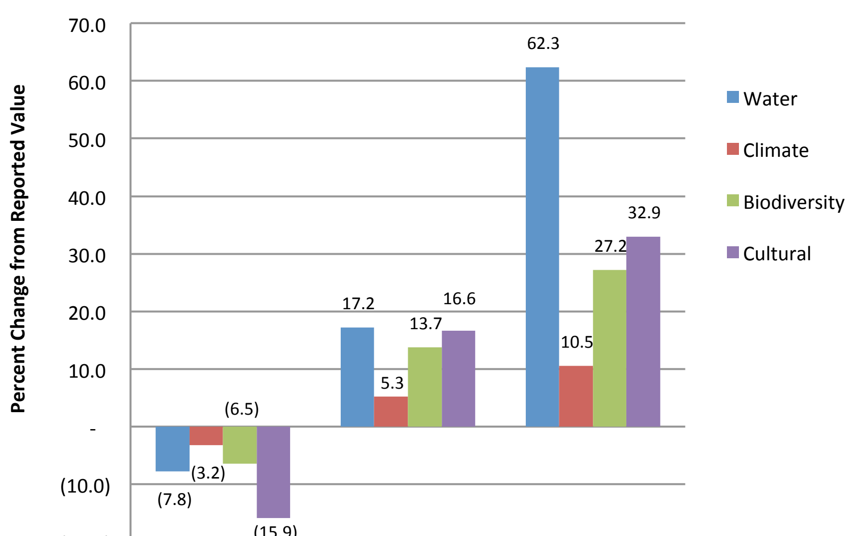


Figure 25. The economic impact (percent change) made to the total assessed value across all services by varying the service values per acre as reported by similar studies.

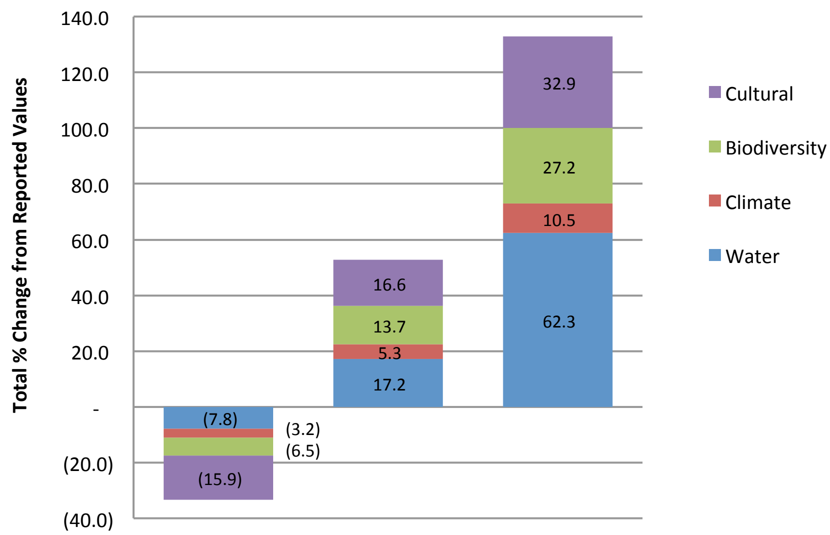


Figure 26. The economic impact (percent change) made to the total assessed value to Texas by varying the service values per acre as reported by similar studies.

Uses, Limitations, and Future Steps

The goal of this assessment was to assess the conservative economic value of forest-based ecosystem services in Texas, a very complicated task, given a state as diverse as Texas. Recognizing these values is paramount to smart land use planning and the long-term sustainability of Texas forests. Expanding the land-use cost-benefit analysis to incorporate the economic impact of these ecosystem services will enable a more realistic and clearer assessment of the full costs and benefits of both the landscape itself, as well as any future landscape changes.

The results of this assessment can be accessed through www.texasforestinfo.com (Figure 27). This interactive website provides a wealth of information about the State's tree and forest resources, as well as the benefits they provide. The "*Forest Ecosystem Values*" application links to the geospatial data used in this assessment, and enables users to view maps, obtain ecosystem service values, and print reports for customized areas of the State.

This assessment quantifies and values only the regulating and cultural ecosystem services provided by Texas forestlands. It does not include the economic estimates associated with commonly assessed goods and services such as fiber, wildlife, and recreation derived from forestlands. Similarly, ecosystem services provided by the collection of street, park and residential trees within urban and community areas were not assessed. Likewise, only forest-based ecosystem services were evaluated. Other lands, such as agricultural, prairie, and rangelands, were not included in this assessment. While these results can be used to assess the effects of forest conversion, the total change in ecosystem service value is largely dependent upon the new land use.

Additionally, this assessment was conducted as a broad, regional evaluation of forestlands in Texas. As such, per acre ecosystem service values were not differentiated between species group, stocking levels, or forest condition, except for the climate regulating service. Regional and eco-regional service values were largely based on the number of forested acres within the respective area, regardless of their composition, stocking, or health. The extent and distribution of forestland across the State was the principal geospatial data input used for this assessment. As a result of the substantial computer processing requirements, this layer was produced at a 250-meter resolution scale. Although this layer was critical to conducting the assessment, a higher resolution dataset would facilitate a more precise evaluation of the ecosystem services provided by Texas forests.

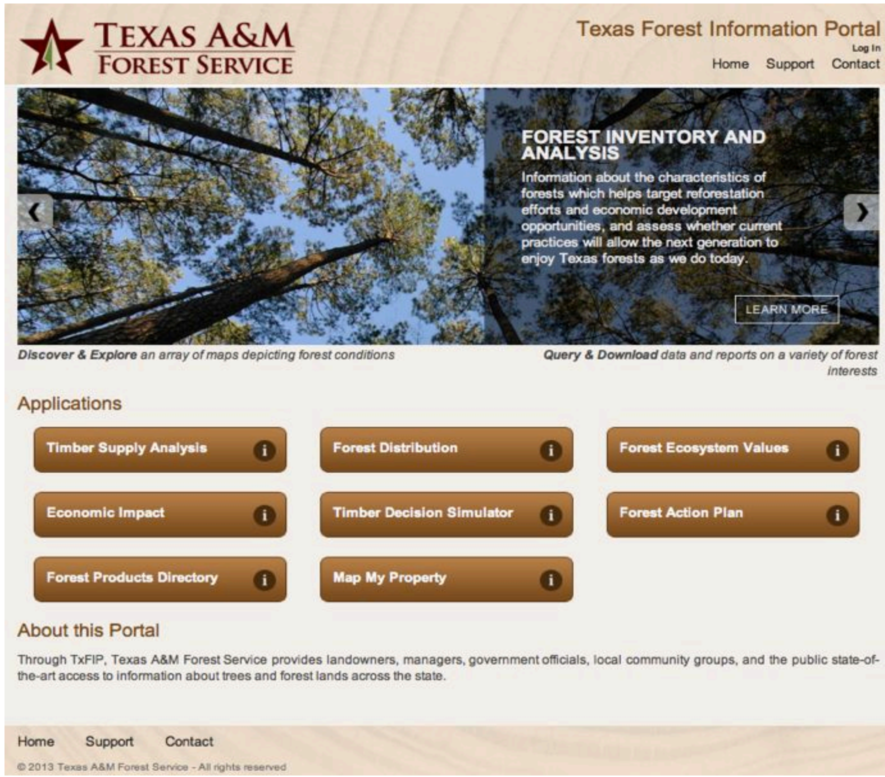


Figure 27.   Screenshot of the Texas A&M Forest Service's Forest Information Portal illustrating the numerous tools for assessing forest resources in Texas.

While there have been many attempts to value ecosystem services across the world, these assessments are still in their infancy and constantly evolving. As these services continue to gain notoriety, additional studies will undoubtedly be conducted, leading to improved economic estimates of forest based ecosystem services in Texas. Future valuation efforts will look to incorporate the most recent economic estimates, identify methodologies that account for the differences in forestland composition, stocking, and health, and utilize an updated, higher resolution (30-meter) geospatial forestland layer. In addition, a comprehensive evaluation of all urban forests (the total collection of trees that grow with urban and community areas) is currently being conducted, and the resulting report will provide an overall ecosystem services assessment for ALL forests and trees in Texas.

Currently, a great deal of effort is ongoing to improve and develop new models (primarily process models) that more accurately assess and predict any number of ecosystem services. Soon, robust models will be available to map, assess, and predict the various ecosystem services to finer detail, thus allowing future efforts to more accurately estimate economic values of ecosystem services provided by forests and woodlands in Texas. For example, promising advancements made by the PINEMAP partnership (Pine Integrated Network: Education, Mitigation, and Adaptation project) are fine tuning models such as *3-PG* (Physiological Principles in Predicting Growth); *WaSSI* (Water Supply Stress Index Ecosystem Services Model); and *TACCIMO* (Template for Assessing Climate Change Impacts and Management Options). Once these models are finalized, TFS will evaluate them for their applicability in valuing forest ecosystem services in Texas.

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APPENDIX A: Assessment Methods

Spatial Data Methodology

The forestland geospatial layer shown in Figure 1 & 2, a 250-meter resolution raster derived from MODIS imagery and provided by the FIA program of the USDA Forest Service, was used extensively throughout this assessment. The value of each pixel is a floating point ranging from 0 to 1, and represents the proportion of each pixel that is forested as imputed from FIA plot data, MODIS imagery, ecoregion, and soils information. The sum of the pixel values multiplied by 15.4440625 acres/pixel equals the total forested acres as estimated by FIA (62.4 million acres). Values for forestland were calculated for the state as a whole, by *East* (43 counties) and *Central/West* (211 counties) Texas (Figure 1), and by project-specific ecoregions *Pine Woodlands, Coastal Woodlands, Post Oak, Hackberry–Oak, Mesquite–Juniper, High Plains*, and *Mountain* (Figure 2). To estimate values by region and ecoregion, county and ecoregion vector files were converted to 250-meter resolution raster files for each region. Pixel values for region rasters were given a value of zero while areas outside each region were given pixel values of NoData. ArcGIS Toolbox>Map Algebra>Raster Calculator was used to create files of forestland within each region. By adding the region layer to the forestland layer, the resulting raster has values for forestland within the region while areas outside the region have values of NoData thus allowing the summation of forestland within the region. The sum of the pixel values multiplied by 15.4440625 acres/pixel equals the total forested acres.

Watershed Service Forest Cover Type Methodology

Rural non-riparian forests

Rural non-riparian forests were estimated from the FIA forestland geospatial layer provided by the USDA Forest Service. This forest cover type was calculated by removing forests in urban, riparian, and wetland areas from the total forest land area. Values for rural non-riparian forestland were calculated for the state as a whole, by *East* (43 counties) and *Central/West* (211 counties) Texas, and by ecoregions as defined in this project including *Pine Woodlands, Coastal Woodlands, Post Oak, Hackberry–Oak, Mesquite–Juniper, High Plains,* and *Mountain*.

Tree species attribute data from the FIA forest type layer were used to estimate the extent of woody plant encroachment where brush control could increase water supply in Central/West Texas. Live oak and ashe-juniper, identified by code XXX and XXX, respectively, were overlaid with a geologic layer showing fractured karst limestone in the Edwards Plateau. Pixel values in the intersecting area greater than 0.6 (representing dense forest cover) were used to calculate the resulting forest area. Mesquite, identified by code 970 (Woodland hardwood group), was overlaid with the Carrizo-Wilcox aquifer recharge area polygon and a well-drained soil layer derived from the State Soil Geographic Database (STATSGO). This same forest type was also overlaid on the Blackland Prairie ecoregion. The intersecting forest areas were calculated.

Rural riparian forests

Rural riparian forests were estimated using three data layers: (1) *Riparian Areas* from the Texas Statewide Assessment of Forest Resources, (2) the *Forestland* layer used for this project, and (3) the *Forested Wetlands* layer used for this project.

The *Riparian Areas* layer was derived from the National Hydrography dataset (NHD) high-resolution flowline data. Since many stream segments within each watershed were missing values for stream order, which was used to determine the width of the riparian area, the RivEX tool version 4.2 (www.rivex.co.uk/) was used to generate these values. Stream orders one to four were buffered by 50 meters, whereas orders greater than four were buffered by 100 meters. The resulting vector file was converted to a 30-meter resolution raster. Since wetland forest cover types may occur in conjunction with riparian areas, they were removed from this layer to avoid double counting. The updated *Riparian Areas* raster, excluding forested wetlands, was then combined with a re-sampled 30-meter resolution *Rural Forestland* layer (forests in urban areas were removed). This was done to determine the proportion of each riparian pixel that is forested.

The region and ecoregion vector files described in the *forestland* layer section above were converted to individual 30-meter resolution rasters to enable the summation of rural riparian forests by region. The sum of the pixel values multiplied by .222395 acres/pixel equals the total area of rural riparian forests.

Within this forestland cover type, the area occupied by salt cedar was delineated to estimate the negative impact on water capture by this species. Since the FIA forest type layer did not include attribute data for salt cedar, NLCD 2006, a 1960s USGS study, and personal knowledge of its extent were used. Pixel reflectance values in known salt cedar occupied areas (such as the Pecos River) were compared to riparian forest species throughout West Texas to estimate its' extent.

Rural wetland forests

Rural wetland forests were identified using Class 90 (Woody Wetlands) of the 30-meter resolution *2006 NLCD*. Wetland forests in urban areas were removed from this layer. The individual 30-meter resolution region and ecoregion rasters were combined with the rural wetland forests raster to enable the summation of rural wetland forests by region. The count of the pixel values multiplied by .222395 acres/pixel equals the total forested wetland acres.

Urban non-riparian forests

Forests in urban areas were identified using the *forestland* layer, 2006 NLCD, and the *U.S. Census Cartographic Boundary* files. Pixel values within the boundary of urbanized areas or urban clusters as defined by the Census were used to create the *Forests in Urban Areas* layer. This layer was then re-sampled to a 30-meter resolution raster, and compared to the *Riparian Areas* and *Forested Wetlands* layers. Overlapping forests were removed. The remaining coverage was classified as urban non-riparian forests, and combined with the individual 30-meter resolution region and ecoregion rasters to enable the summation of this forest type by region. The count of the pixel values in this layer multiplied by .222395 acres/pixel equals the total urban non-riparian forest acres.

Urban riparian forests

Urban riparian forests were identified by combining the re-sampled 30-meter resolution *Forests in Urban Areas* layer with the *Riparian Areas* layer and extracting the overlapping forests, which were classified as urban riparian forests. The extracted layer was combined with the individual 30-meter resolution region and ecoregion rasters to enable the summation of this forest type by region. The count of the pixel values multiplied by .222395 acres/pixel equals the total urban riparian forest acres.

Urban wetland forests

Urban wetland forests were identified using the *Forested Wetlands* layer and the *U.S. Census Cartographic Boundary* files. Forested wetlands within the boundary of urbanized areas or urban clusters as defined by the census were extracted and classified as *Urban Wetland Forests*. The extracted layer was combined with the individual 30-meter resolution region and ecoregion rasters to enable the summation of this forest type by region. The count of the pixel values multiplied by .222395 acres/pixel equals the total urban wetland forest acres.

Valuation of Carbon Storage and Carbon Sequestration

There is a difference in the value of carbon storage and carbon sequestration. Much of the economic value of carbon storage in the forest ecosystem is lost if the vegetation is lost to wildfire, insects, disease, and extreme weather events or if the forest is converted to other uses. Therefore, the value of carbon storage is a snapshot of the value of carbon stored within forests at a given point in time. The value of carbon sequestration, on the other hand, is the value of the net annual fixation of carbon in a growing forest.

A significant volume of studies exists that estimates the value of carbon based on an economic cost to society, (often called the "social cost of carbon") from damages caused by emitting additional carbon dioxide into the atmosphere. Most of the studies on social cost of carbon use models that integrate climate processes, economic growth and the interactions between them into a simulated framework. Normally, the estimates are developed using either the cost benefit approach or the marginal cost approach. The estimated social cost of carbon varies greatly depending on the choice of climate change model, assumption of economic growth path and rate, social discount rate, assumption of adaptation as well as other economic and climate variables. The Intergovernmental Panel on Climate Change's (IPCC) Working Group III suggested the marginal damage cost of carbon to be within a range of $5 - $197/t (in 1990 constant prices) based on a review of existing studies. A later literature review by Clarkson and Deyes (2002) suggested a range of $62 - $250/tC with an average of $125/tC (in 2000 constant prices). The meta-analysis of 211 existing studies on social cost of carbon by Tol (2008) found a mean of $23/tC. In 2010, the U.S. government's Interagency Working Group on Social Cost of Carbon estimated the social cost of carbon at a mean of $21/tC with a range of $5 - $65/tC (in 2007 constant prices). The proposed estimate was developed for use in regulatory impact analysis (mostly cost-benefit analysis). A recent study by Nordhaus (2011) estimated the social cost of carbon to be $44 - $48/tC (in 2005 constant prices).

Another way to estimate the value of carbon is the observed transaction prices at voluntary carbon markets. As noted by Moore et al. (2011), the Chicago Climate Exchange (CCX) had a mean price of \$2.1/tCO_2e (\$7.7/tC) with a high of \$7.4/tCO_2e (\$27.11/tC) and a low of \$0.05/tCO_2e (\$0.2/tC). Forest Trends has been tracking the status and trend of the global voluntary carbon market based on surveys of offset suppliers, major exchanges, and major registries around the world. According to their most recent report (Peters-Stanley and Hamilton 2012), the average volume-weighted carbon offset price was \$6.2/tCO_2e (\$22.7/tC) for the global market and \$6/tCO_2e (\$22/tC) for the U.S. in 2011.

The value of carbon can also be estimated based on the value of permit for CO_2 emissions under certain regulatory compliance. For example, an EU allowance (EUA) is a permit to emit one metric ton of CO_2 under the European Union Emission Trading Scheme. According to Point Carbon, the average price for a metric ton of CO_2 emission was around €7.2 in 2011, or $32.6 per metric ton of carbon. Additional methods exist to estimate the value of carbon which include estimates based on carbon tax (or fees), replacement costs, or the costs of timber income foregone for protecting carbon stored in forest ecosystems (Solberg, 1997; Kulshreshtha et al., 2000; Haener and Admowicz, 2000; Anielski and Wilson, 2009). In this study, $22/tC was adopted as the value of carbon stored and sequestered in the forests. This is most likely close to the lower end of the existing estimates on carbon values and was chosen as a conservative approximation of the value of carbon. The actual values of the carbon associated with Texas' forests are almost certainly higher.

Incorporating REAP Diversity Layers in Biodiversity Assessment Methodology

The *Composite* map is the summary of the REAP *Diversity*, *Rarity*, and *Sustainability* layers. The *Diversity* layer shows land cover continuity and consists of three sub-layers: (1) appropriateness of land cover, (2) contiguous size of undeveloped area, and (3) Shannon land cover diversity. The *Rarity* layer was designed to show species rarity and consists of four sub-layers: (1) vegetation rarity, (2) natural heritage rank, (3) taxonomic richness, and (4) rare species richness. The *Sustainability* layer describes resiliency and consists of several sub-layers: (1) contiguous land cover type, (2) regularity of ecosystem boundary, (3) appropriateness of land cover, (4) waterway obstruction, and (5) road density; and stressors: (1) airport noise, (2) Superfund National Priority List (NPL) and state Superfund Sites, (3) water quality, (4) air quality,(5) Resource Conservation and Recovery Act (RCRA) Treatment – Storage - Disposal sites (TSD), corrective action and state Voluntary Cleanup Program (VCP) Sites, and (6) urban/agricultural disturbance.

The original *Composite* layer, obtained directly from Regional Ecological Assessment Protocol (REAP), included regional data encompassing all of Arkansas, Louisiana, Oklahoma, New Mexico, and Texas. The Texas area was clipped out of this regional layer and reclassified to the layer symbolization supplied by REAP: 1=top 1%, 10=2-10%, 25=11-25%, 50=26-50%, and 100=51-100%. These classes are based on the whole region and not just Texas.

Cultural Services – Stated Choice Modeling Methodology

Under the random utility theory, an individual's utility function is composed of two components: a deterministic component and a random component. The utility of individual *i* for alternative *j* (u_{ij}) is:

$$u_{ij} = v_{ij} + \varepsilon_{ij},$$

where u_{ij} is the true utility, v_{ij} is the observable deterministic component of the utility for individual *i* to choose alternative *j*, and ε_{ij} is the random component. Due to the random component, the analysis can be treated as one of probabilistic choice. The probability that individual *i* chooses alternative *j* over alternative *h*, can be expressed as the probability that the utility associated with alternative *j* exceeds that associated with alternative *h*:

$$\Pr\,(u_{ij} > u_{ih}) = \Pr\,(v_{ij} - v_{ih} > \varepsilon_{ih} - \varepsilon_{ij})$$

For simplicity, the observable component of the utility function ($\boldsymbol{v}$) is assumed to be linear and additively separable. It is a function of observable attributes (*k*) such as consumption of certain goods or socio-economic characteristics of the individual. The value $\delta_i = \varepsilon_{ik} - \varepsilon_{ij}$ is assumed to be independently and identically distributed with a Gumbel distribution. Therefore, the probability that individual *i* choose alternative *j* over alternative *h* is:

$$\Pr\,(u_{ij} > u_{ih}) = \frac{e^{\sum_{g=1}^{k}\beta_g x_{ijg}}}{e^{\sum_{g=1}^{k}\beta_g x_{ijg}} + e^{\sum_{g=1}^{k}\beta_g x_{ihg}}}$$

where, *g*=1,...,*k*, represents one of the *k* observable attributes. β_g is the coefficient associated with attribute *g*. If the choice set includes more than two alternatives, the probability of individual i choosing alternative *j* is:

$$\Pr(choosing\ alternative\ j|Choice\ set\ S)) = \frac{e^{\sum_{g=1}^{k}\beta_g x_{ijg}}}{\sum_{h\in S} e^{\sum_{g=1}^{k}\beta_g x_{ihg}}}.$$

TEXAS STATEWIDE ASSESSMENT OF FOREST ECOSYSTEM SERVICES

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