Total ecosystem services values (TEV) in southwest Florida: The ECOSERVE method

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Abstract Ecosystem services are the multitude of resources and processes that are supplied by natural ecosystems. This includes a wide range of natural processes that help sustain and fulfill human life, such as: purifying air and water, detoxifying and decomposing wastes in water, pollinating natural vegetation, cycling and moving nutrients, protecting coastal shores from erosion by waves, moderating weather extremes and their impacts, and providing aesthetic beauty and intellectual stimulation that lift the human spirit. A total ecosystem services quantification using the ECOSERVE mapping methodology was developed by the Southwest Florida Regional Planning Council in partnership with the Charlotte Harbor National Estuary Program (CHNEP) and the Sanibel-Captiva Conservation Foundation in the project "Estimating and Forecasting Ecosystem Services within Pine Island Sound, Sanibel Island, Captiva Island, North Captiva Island, Cayo Costa Island, Useppa Island, Other Islands of the Sound, and the Nearshore Gulf of Mexico" (Beever and Walker 2013), linking the derived ecosystem function measurements with a geo-spatially positioned ecosystem services database, derived from wetland functional analyses that are utilized to forecast, evaluate and report trends in wetlands ecosystem services.

Keywords Ecosystem services, GIS, Pine Island Sound, Sanibel, decision-making, sea level rise

Introduction and Background

The natural world, its biodiversity, and its constituent ecosystems are critically important to human well-being and economic prosperity, but are consistently undervalued in conventional economic analyses and decision-making. (CAV-SARTE 2004, Samuelson 1983) Ecosystems and the services they deliver underpin our very existence. Humans depend on these ecosystem services to produce food, regulate water supplies and climate, and breakdown waste products. Humans also value ecosystem services in less obvious ways: contact with nature gives pleasure, provides recreation and is known to have positive impacts on long-term health and happiness (UK National Ecosystem Assessment 2011). Human societies get many benefits from the natural environment. In Southwest Florida, we are well aware of how important eco-tourism, sport and commercial fishing, and natural products such as locally produced fruits, vegetables and honey are to our regional economy. The natural environment also provides, for free, services that we would otherwise have to pay for, in both capital outlay, and operation and maintenance costs.

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The United Nations 2004 Millennium Ecosystem Assessment grouped ecosystem services into four broad categories: Provisioning, such as the production of food and water; Regulating, such as the control of climate and disease; Supporting (Habitat), such as nutrient cycles and crop pollination; and Cultural (Socio-economic), such as spiritual and recreational benefits.

Ecosystem services values can be useful in justifying grant funding and in leveraging restoration dollars. These values can also used by decision-makers when establishing and maintaining conservation lands, siting utilities, making development decisions, putting numbers to the impacts associated with decisions, and adding data when critical trade-offs are discussed. Discussions on retaining local government land acquisition programs in Lee County and Collier County are examples of the use of ecosystem services values in decision-making.

Recognition of how ecosystems provide complex services to mankind are documented in Western culture to at least Plato (c. 400 BC) (Marsh 1965). The term 'environmental services' was introduced in a 1970 report of the Study of Critical Environmental Problems (SCEP 1970), which listed services including insect pollination, fisheries, climate regulation and flood control. In following years, variations of the term were used, but eventually 'ecosystem services' became the standard in scientific literature (Ehrlich and Ehrlich 1981). Modern expansions of the ecosystem services concept include socio-economic and conservation objectives (de Groot et al. 2012).

There has been some resistance, particularly from life-science academics and environmentalists, to establishing monetary values for ecosystem services because it is difficult to capture the total value and there is always the potential to risk under-valuing the services. However, assigning value to ecosystem services is a necessary and important tool to demonstrate the economic values being lost to society. Ecosystem evaluation is a field that requires great amounts of innovation; developing communication tools that can relate tangible value to ecosystem services will be meaningful in protecting healthy watersheds. The important message is that conservation provides myriad economic and social benefits at the local level. Protecting these systems will provide society with greater economic security, healthy, bountiful fisheries, a higher quality of life and clean drinking water (Dlugolecki 2012).

Materials and Methods

The project locations assessed by the ECOSERVE method, so far include the greater Pine Island system, the Lee County Conservation 2020 lands, and the Conservation Collier lands.

Pine Island Sound Project - Pine Island Sound is located in Lee County, Florida, lying between Pine Island and the barrier islands of Sanibel Island, Captiva Island, North Captiva Island and Cayo Costa, which separate the Sound from the Gulf of Mexico (Figure 1). The Sound connects to Gasparilla Sound and Charlotte Harbor to the north, and to San Carlos Bay and the Caloosahatchee River to the south. The Sound is conterminous with the Pine Island Sound Aquatic Preserve, which was established in 1970 and consists of 220 km^2 (54,000 acres) of submerged land. Important habitats in the Sound include mangrove forests, seagrass beds, salt marshes, oyster reefs and tidal flats. Pine Island Sound has the most extensive sea grass beds in the greater Charlotte Harbor complex. Large areas of oyster reef-hard bottom communities are comparatively rare in the

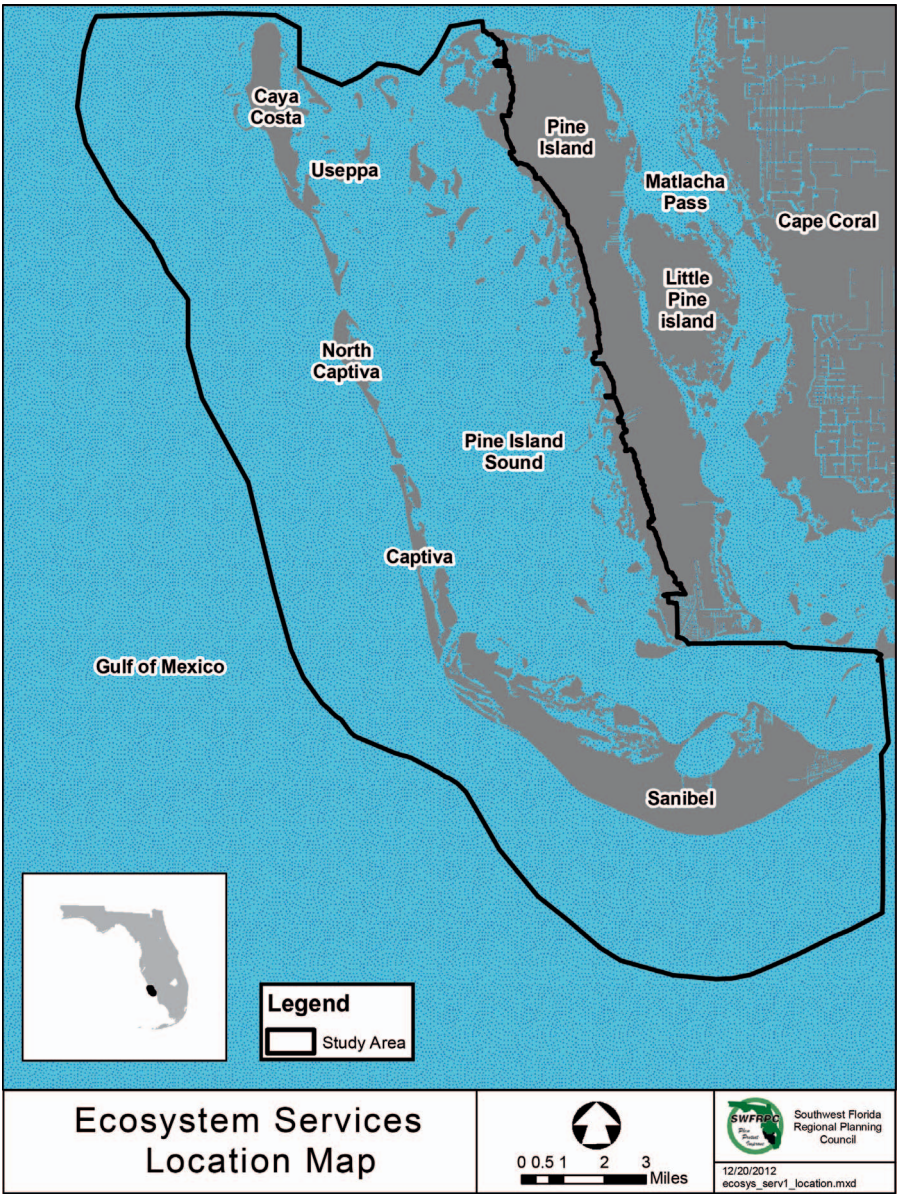

Figure 1. Pine Island Sound Project Study Area.

estuary, and are often found associated with the shoreline, yet at a distance from it. The total estimated mangrove acreage for the Pine Island Sound/Matlacha sub basin is 7,732 hectares (19,107 acres). The mangroves in this region are extensive and fringe all of the protected shorelines of the barrier islands. The mosaics of mangroves in the southern portion of this region, on the northern coast of Sanibel Island, are particularly noted for the living resources they support, such as large populations of endangered roseate spoonbills. The establishment of ecosystem services values for

this ecologically rich area was among the first valuations of this type in this region and served as a model for later evaluations of conservation lands in Lee and Collier Counties.

For Pine Island Sound we identified all the existing habitat types found in the study area through GIS analysis of existing aerial imagery. The most recent available GIS layers were utilized included the NOAA bathymetry (CHNEP 2011), the CHNEP Benthic Habitat Map (Photo Science 2007), the SFWMD seagrass mapping (FWC 2011), the SFWMD land use map (2008), and the 2011 salt marsh by type map created by the SWFRPC in the salt marsh study (Beever et al. 2012).

Functional assessment methods utilized in Beever et al. (2013) including UMAM, HGM, and WRAP, were utilized, linking the derived ecosystem function measurements with geo-spatially positioned ecosystem services information. The combined land and bottom cover map was constructed in the following order beginning with the NOAA bathymetry layer, the CHNEP Benthic Habitat Map, the SFWMD seagrass map, the SFWMD land-use map and finally the salt marsh by type map. Later layers in the sequence took priority over earlier layers. For small edges where no land use was indicated, usually at the meeting of the benthic layer and land cover, the blank area was assigned the value of the nearest adjacent benthic or bathymetric value.

The range and quantity of ecosystem services provided by existing habitats was estimated, including the marine, estuarine and freshwater wetlands, and associated native uplands of the islands were estimated. Dollar values for ecosystem services were obtained either directly or through calculation from the following: Allsopp et al. (2008), Beever III and Cairns (2002), Beever III (2011), Beever III et al. (2012), Bolund and Hunhammar (1999), Casey and Kroeger (2008), Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems (CAVSARTE) (2004), Conservation International (2008), Costanza et al. (1997), Costanza (2008), Costanza et al. (2008), Dale and Polasky (2007), Dlugolecki (2012), Engeman et al. (2008), Goulder and Kennedy (2007), Goulder and Kennedy (2011), Hazen and Sawyer (1998), Henderson and O'Neil (2003), Isaacs et al. (2009), Krieger (2001), Kroeger and Casey (2007), Kroeger et al. (2008), Lee County Visitor and Convention Bureau (2002), Losey and Vaughan (2006), Lugo and Brinson (1979), McKee (2011), McLeod and Salm (2006), Metzger et al. (2006), Morales (1980), Paling et al. (2009), Pidwirny (2006), Vo et al. (2012), Sathirathai (2003), South Florida Water Management District (2007), Spaninks and van Beukering (1997), American Sportfishing Association (2006), USFWS (2007), UK National Ecosystem Assessment (2011), Weisskoff (2012), and Wells et al. (2006).

For developed land use types (Florida Land Use Cover Classification System (FLUCCS) codes 100, 200, and 800), the Total Ecosystem Services Value (TEV) calculation involved the estimation of the amount of non-impervious surface on the specific land use type and the vegetation type on that lands use. This information was obtained from Thompson et al. (2011), the Sanibel Plan (City of Sanibel 2012), the U.S. Census Bureau (2010) and the Sanibel-Captiva Conservation Foundation.

We produced a current map of ecological services value topographies (ECOSERVE) using combined GIS map and the total estimated ecosystem services value for each habitat type. This provides a visual representation of the geographic distribution of the TEV within the study area.

We then calculated the TEV for the total acreage of each habitat type within the study area. Each dollar value for ecosystem service provided by a particular habitat was specified for its year of estimation. The dollar value of the ecosystem service estimate was then normalized using the inflation rate from the consumer price index (Bureau of Labor Statistics 2012) to a 2012 dollar value using the appropriate inflation multiplier. The resulting ecosystem service value per acre was then multiplied by the number of acres of that habitat type to obtain the total ecosystem services value for that habitat type in the study area. All of the habitat values were then summed to obtain a total ecosystem services value for the entire Pine Island Sound study area (Beever and Walker 2013).

An ecosystem services topography (ECOSERVE) geographic information system (GIS) layer was generated from the TEV value per acre mapped within each habitat. This geographic representation of the TEV for the study area provides a visual representation of where the highest value habitats are and how different changes on the landscape can change and transform the value and nature of the ecosystem services provided by the estuary and barrier islands (Figure 2).

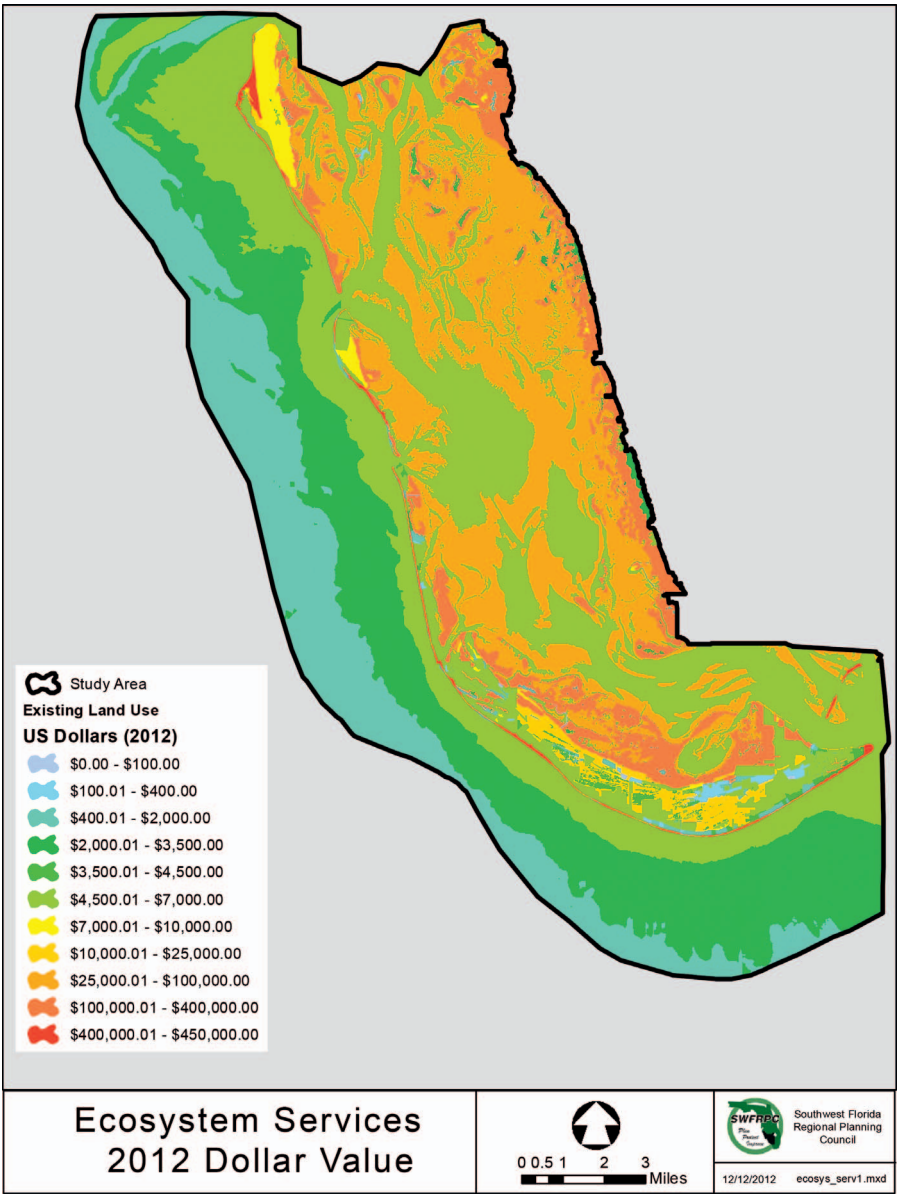

Figure 2. Ecosystem Services 2012 Dollar Values in the Year 2012 (Baseline Condition) for the Study Area.

The ECOSERVE map can be combined with other geographic information system (GIS) layers for functional analyses by service type, by geographic boundary and in combination. This process is a tool that can generate projections of ecosystem services that may result from land use changes, anticipated climate changes, natural and man-made disasters, the implementation of alternative wetland protection and land conservation programs or the landscape scenario which

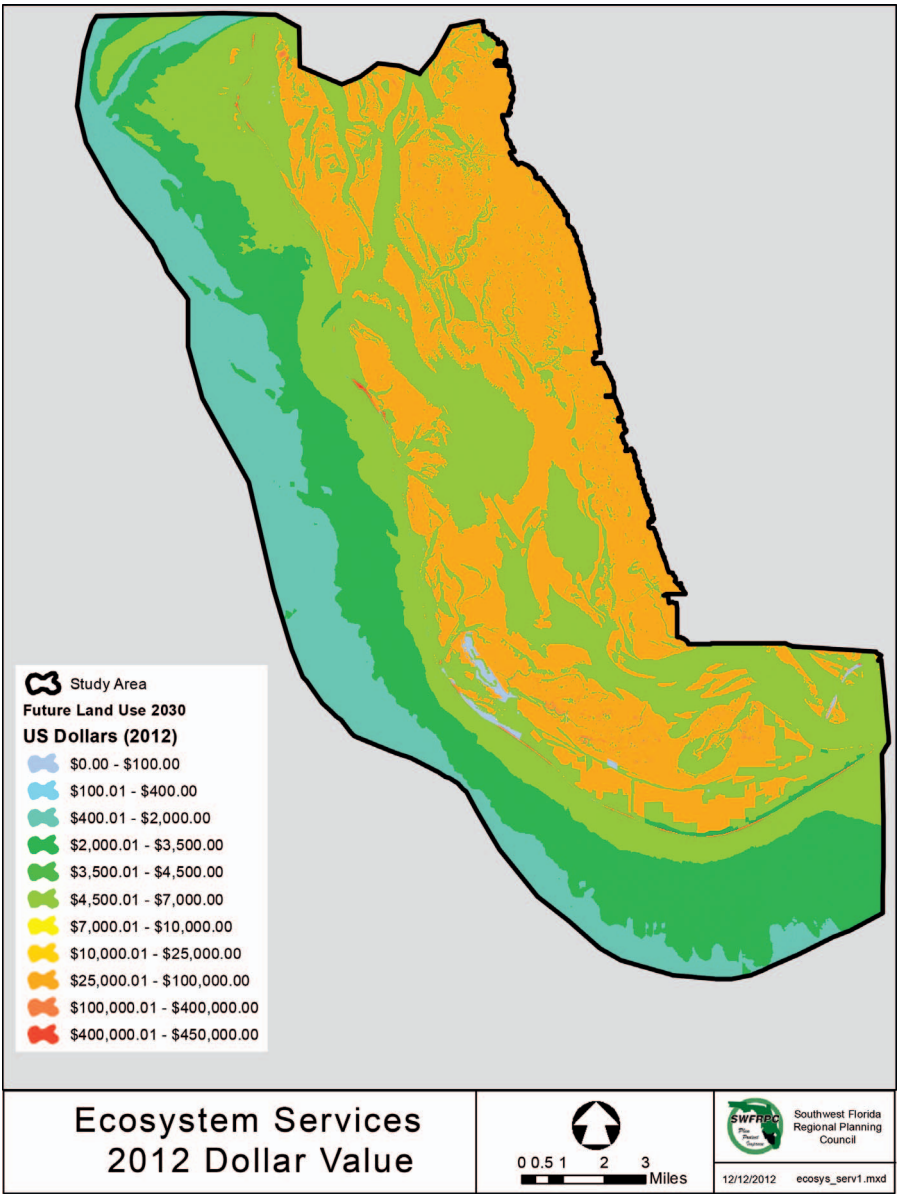

Figure 3. Ecosystem Services 2012 Dollar Values Projected for the Year 2030 (Future Land Use Map Condition) for the Study Area.

would reflect the eventualities resulting from making no changes to current land use, management or regulatory policy.

We generated two alternate future ECOSERVE topographies related to the anticipated land use changes that come with the future land use projection for the year 2030 (Figure 3) and for a one-foot sea level rise in the study area (Figure 4).

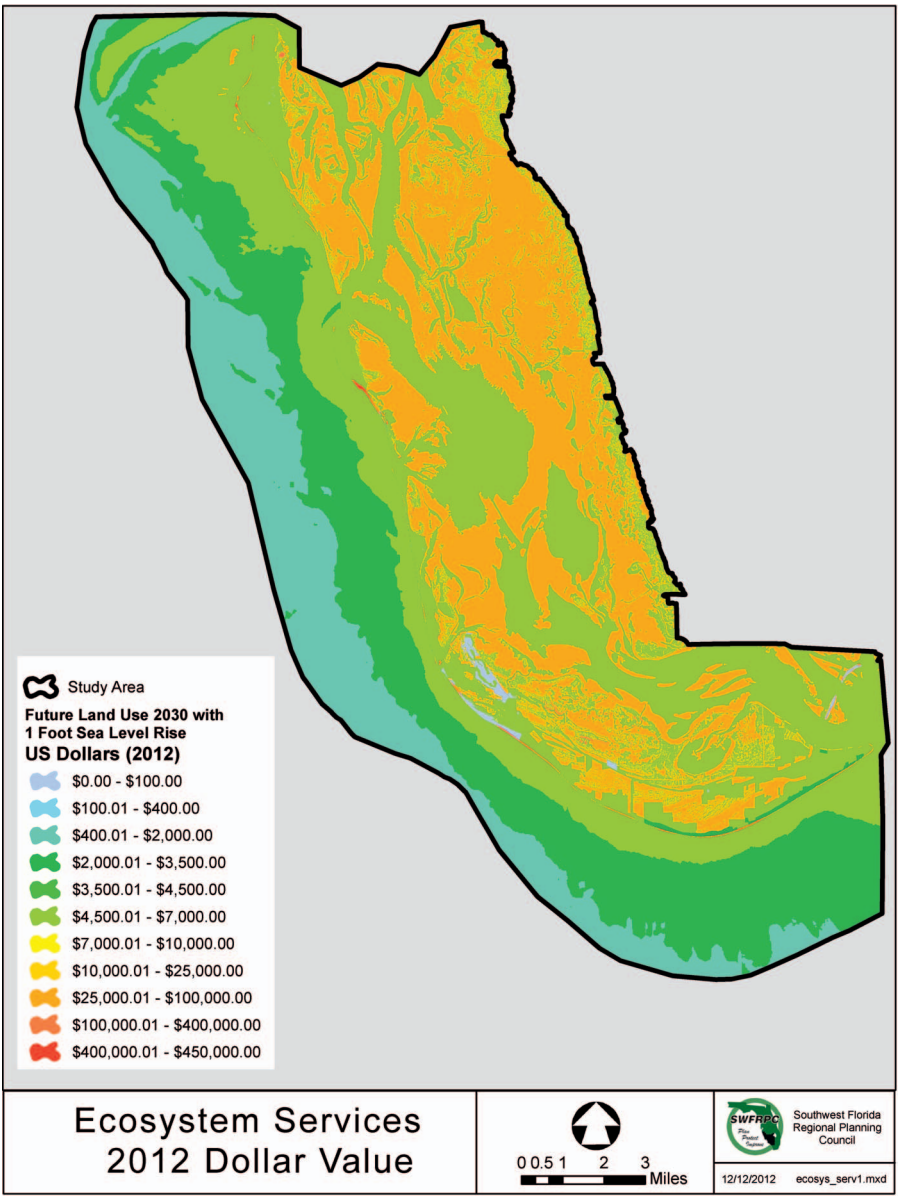

Figure 4. Integrated Ecosystem Services 2012 Dollar Values Projected for the Year 2100 (80% IPCC probability) with 1 foot of Sea Level Rise for the Study Area.

Lee County Conservation 2020 study. All the 76 existing habitat types found on Conservation 2020 lands were identified by Lee County staff. The most recent available tabulation was utilized. The total area of Conservation 2020 lands is 10,088 hectares (24,928 acres). The largest habitat type is Mesic Pine Flatwoods which constitutes 19.3% of all Conservation 2020 lands. Mesic Pine Flatwoods, Wet Flatwoods, Disturbed Mesic Pine Flatwoods, Mangrove Swamp, Disturbed Wet

Pine Flatwoods, and Strand Swamp make up 51.5 % of all the Conservation 2020 lands. For the Conservation 2020 lands project the range and quantity of ecosystem services provided by existing habitats was estimated utilizing the methods developed by Beever and Walker (2013) described above. For habitats not included in the Pine Island Sound study (Beever and Walker 2013), dollar values for ecosystem services were obtained either directly or through calculation from the same sources (Beever 2013a). When a habitat was indicated as disturbed a 50% valuation of the full TEV for that habitat type was utilized based on consultation with Lee County staff concerning the extent of disturbance. To estimate ecosystem service values, we developed a table analogous to the Pine Island Sound study, including 2012 dollar normalizations (Beever 2013a).

Conservation Collier. As of February 2014, Conservation Collier lands made up approximately 0.02% of Collier County's land, with 19 properties totaling 4,054.7 acres. All the 57 existing habitat types found on Conservation Collier lands were identified by Collier County staff. The most recent available tabulation was utilized. The total area of Conservation Collier lands is 1,640.9 hectares (4,054.7 acres). The largest habitat type is Improved Pasture which constitutes 17.5% of all Conservation Collier lands. Pine Flatwoods are the most common type of native habitat constituting 8.3% of Conservation Collier Lands. Disturbed depression marsh is the most common freshwater wetland habitat (7.8%) and mangroves are the most common saltwater wetland habitat (7.6%). Improved Pasture, Pine Flatwoods, disturbed Depression Marsh, Mangrove Swamp, Upland Mixed Forest, Mixed Wetland Hardwoods, Wetland Scrub, and Cypress Swamp make up 64.4% of all the Conservation Collier lands.

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Results

These studies identify the range and quantity of ecosystem services provided by marine, estuarine and freshwater wetlands and native upland habitat and to determine how the functional types of wetlands and native uplands, their distribution and position in the landscape, and their ecological condition affects ecosystem services within the Pine Island Sound, and on Sanibel Island, Captiva Island, North Captiva Island, Cayo Costa Island, Useppa Island and Islands of the Sound; the Lee County Conservation 2020 lands, and the Collier Conservation lands.

Based on current calculations of Total Ecosystem Services Value (TEV) for the Pine Island Sound Study Area the 2012 TEV is $7,033,362,634.63. (Figure 2) (Beever and Walker 2013). It is notable that the majority (98.6%) of the TEV is found in the top seven habitats including mangrove swamp (38.3%), continuous seagrass beds (36.5%) estuarine embayments (10.7%), swimming beaches (5.4%), the nearshore Gulf of Mexico (3.7%), discontinuous sea grass beds (2.3%), and unvegetated shallow subtidal bottoms (1.8%). These seven habitats make up 83.9% of the physical area of the study area.

Projecting to the build-out scenarios envisioned on the Future Land Use (FLU) Map for the study area which projects to a future at 2030 and beyond it is possible to see using the ECOSERVE what the future anticipated ecosystem services value would be. The future land use map is not as detailed in specific development and conservation land covers and uses simplified land use covers. Subsequently some cover types are subsumed into large categories such as Coastal Rural, Conservation Lands Upland, Conservation Lands Wetland, Outer Island, Outlying Suburban, Public Facilitates, Rural, Suburban, Urban Community, and Wetlands. For these larger land use categories mean TEV per acre were derived from the specific land uses included in that category (Beever and Walker 2013). The resulting FLU 2030 map indicated loss of native upland and wetland habitat, some conversions of existing developed land uses to more intense developed land uses, and the elimination of most exotic plant communities with their development into human land uses (Figure 4). In the land use changes associated with the 2030 build out the following land use categories are no longer present: mobile home parks, dry prairie, pine flatwoods, Brazilian pepper, upland melaleuca, saltwater ponds, shrub black mangrove, freshwater marsh, algal marsh, and saltern. The resulting landscape has a reduced TEV Future Land Use Projection (2030) (TEV) for the Pine Island Sound area of $5,146,537,673.59 measured in 2012 dollars. (Beever and Walker 2013). This constitutes a 26.83% loss of 2012 TEV. If a projected level of inflation between 2012 and 2030 is applied then the dollar value of the TEV would increase. This study does not have a projection for what that inflation rate might be since in the prior 18 year period inflation rates have ranged from 0.03 to 4.3 per year with an average of 2.47 $\pm$ 1.02 (U.S. Bureau of Labor Statistics 2012). If one assumes the same rates of inflation (which the authors do not consider likely) then inflation would make up the loss of TEV for a total of $7,434,688,323.27 in 2030 dollars. Of course those 2030 dollars would be worth $0.69 in 2012 currency.

Projecting to a future with the build-out scenarios envisioned on the Future 2030 Land Use Map and a one foot sea level rise in the study area it is possible to project the future anticipated ecosystem services values of the resulting landscape. The point at which one-foot of additional sea level will occur in the project study area depends on several variables that influence the local relative sea level rise, including; global sea level rise from thermal expansion, global sea level rise from non-replaced land ice melt; local sediment deposition; local accretion from wetland plant activity; local accretion from storm effects; local erosion from storm effects and long term erosive forces; human mediated sediment loss including shoreline hardening, disruption of coastal dynamics, reduction of alluvial deposition by dams and water control structures: plate tectonic lift, recession and tilt; and the geomorphic migration of barrier islands.

The current measured sea level rise rate for Lee County is approximately 9 inches in 100 years. Assuming this rate continued without acceleration then a one-foot sea level rise above 2012 levels would be attained in the year 2162.

The resulting one-foot sea level rise map (1FSLR) map indicates significant loss of native upland and wetland habitat, some conversions of existing developed land uses to open water, and the elimination of most exotic plant communities (Beever and Walker 2013). The resulting landscape has a Future Land Use Projection of Total Ecosystem Services Value (TEV) for the Pine Island Sound study area with the Future Land Use Projection (2030) and a one foot of sea level rise of $4,184,956,813.96.

The effect of sea level rise varies with the habitat type. It is important to remember that while a habitat may change from a current above water land cover to an open water submerged condition that the new open water habitat has an ecosystem services values that must be accounted for. If only the loss of above water habits to open water is accounted for than the TEV loss in the study area for a 1 foot sea level rise is $4,019,726,568.16. However, the gain of open water generates $165,230,245.80 of TEV with 1 foot sea level rise. Therefore the net loss of TEV from sea level rise in the study area for 1 foot of sea level rise separate from the 2030 land use changes is $1,126,811,105.43. This is a 16.0% loss of 2012 TEV from the sea level rise alone. Combining the sea level rise of 1 foot with the future land use changes results in a $3,013,636,066.47 loss of TEV. This constitutes a 42.9% loss of 2012 TEV.

The establishment of ecosystem services values for the ecologically rich Conservation 2020 lands was the second valuation using ECOSERVE in Lee County. These ecosystem services values can be used by decision-makers when establishing and maintaining conservation lands, siting utilities, or making development decisions, putting numbers to the impacts associated with those decisions, and adding data when critical trade-offs are being discussed. These values will also be useful in justifying other grant funding and in leveraging future restoration dollars. The output of this project is an assessment of the total ecosystem services provided by all habitat types on the Conservation 2020 lands in Lee County, Florida. This assessment is available to the local governments and the public to assist in planning for use in developing conservation plans. This work was intended to identify the range and quantity of ecosystem services provided by all the land covers types on Conservation 2020 lands including marine, estuarine and freshwater wetlands and native upland habitat, and disturbed habitats.

Based on current calculations the 2012 TEV of the Conservation 2020 lands is $628,865,027.93 (Beever 2013a). It is notable that the majority (92.5 %) of the TEV is found in the top nine habitats including mangrove swamp (63.3%), mesic flatwoods (15.1%) wet flatwoods (3.7%), mesic flatwoods - disturbed (2.6%), mangrove swamp - disturbed (2.2%), strand swamp (2.0%), scrubby flatwoods (1.47%), depression marsh (1.1%), and wet flatwoods - disturbed (1.8%). These nine habitats make up 54.6% of the physical area of the Conservation 2020 lands.

Estimating ecosystem services values for the diverse Conservation Collier lands was the third valuation, following Beever and Walker (2013) and Beever (2013a) using ECOSERVE in southwest Florida. The output of this

project is an assessment of the total ecosystem services provided by all habitat types on the Conservation Collier properties, including a detailed accounting of how mangrove habitat value was derived. This assessment will be made available to the local government and the public to assist in planning for use in developing the Collier County conservation plans. This work is intended to identify the range and quantity of ecosystem services provided by all the land covers types on Conservation Collier lands including marine, estuarine and freshwater wetlands and native upland habitat, and disturbed habitats.

The calculations the 2013 TEV of the Conservation Collier property is $144,988,312.22 per year (Beever 2013b Table 1). Note that this only includes the Collier County owned lands in the Conservation Collier program, a small subset of the total of all the conservation lands in Collier County. The majority (90.6 %) of the TEV for Conservation Collier property is found in the top twelve habitats including mangrove swamp (58.1%), pine flatwoods (7.3%) upland mixed forest (5.6%), mixed wetland hardwoods (3.1%), cypress (2.9%), wetland scrub (2.6%), depression marsh (2.1%), wetland forest mixed (2.0%), upland mixed forest disturbed (1.6%), depression marsh disturbed (1.6%), bottomland forest (1.4%), cypress- cabbage palm-pine (1.2%) and saltwater marsh (1.1%). These twelve habitats make up 64.6% of the physical area of the Conservation Collier property.

Discussion and Conclusions

The output of this project is an assessment of the total ecosystem services provided by all habitat types in the Pine Island Sound, Sanibel Island, and Captiva Island; Lee County Conservation 2020 lands; and the Conservation Collier lands. These assessments have been made available to local governments, state agencies, federal entities and the public for use in developing wetlands and conservation planning, restoration and enhancement plans.

In addition, ecosystem services topography (ECOSERVE) layers were generated that can be combined with other ecosystem services layers for functional analyses by geographic boundary (watershed, municipality, county, etc.). Projections of alternate futures of ecosystem services resulting from land use changes and anticipated climate changes were completed.

The ECOSERVE method can be utilized to forecast and back cast alternate future and past landscapes. With more time and funding we could look at increased sea level rise extents, the benefits and costs of different land acquisitions, the consequences in terms of ecosystem services of various changes in wetland and upland extents resulting from restoration or development plans, the consequences of natural and man-made disasters, the implementation of alternative wetland protection and land conservation programs, as well as the potential impacts of making no changes to current land use, management, or regulatory policy. Utilization of the ECOSERVE layers will allow permit reviewers to evaluate the impact, for example, of alternative project site designs including reduction of areas of wetland impacts.

Subsequently the tables associated with the ECOSERVE mapping can include: quantification of observed habitat condition information linked to ecosystem services and their contributions to human well-being; quantification of the pollution prevention or mitigation services (e.g. chemical pollutant removal, sediment removal) provided by ecosystems with a comparison to the cost of providing them through built infrastructure; quantification by habitat of the amount of food or fiber produced per unit area in well-protected areas versus that of poorly protected or unprotected areas; the economic value of recreational opportunities provided by a specific habitat provision or by protection of fishable/swimmable water; construction costs avoided by the presence of habitats that slow and absorb floodwaters (flow mitigation or flood control).

Given more time and resources the maps and tables of this project could be improved by a detailed mapping of mangrove forest type to better estimate the ecosystem services provided by each type and better represent the relative functions of each forest type in location and landscape. As indicated by an internal separate analysis of salt marsh combined average versus salt marsh by detailed type estimates significant TEV differences can be obtained. We would expect the difference for a detailed mangrove forest type could be even more pronounced. Another refinement would be to apply a sea grass extent light extinction model to predict future sea grass extent losses as estuarine waters deepen. In this analysis the level of sea level rise (one foot) would not cause major sea grass bed losses as new shallow water is generated. With higher level of sea level rise the deeper edge of sea grass beds would move landward as light attenuation losses occurred in the deeper waters.

Another potential future application could be the ecosystem services values of the conservation easements (Beever and Walker 2015). This could demonstrate the ecosystem services provided by easements in contrast to public acquisitions that may have additional values such as of public access recreation.

More alternate futures could be evaluated with additional climate change perturbations, alternate land use plans, and regulatory environments. The differential benthic habitats in the Gulf of Mexico could be further refined and mapped with methods utilized in identifying the source locations of benthic drift algae.

This development of the ArcGIS-friendly ECOSERVE protocol for statistical and geographical analysis and interpretation can be used with the types of information generated by surveys of ecological condition indicators to quantify ecosystem services. ECOSERVE can be used to quantify the relative importance of perturbation stressors (e.g. land clearing, hydrologic alteration, development, climate change) that impact habitats and the ecosystem services they provide, ECOSERVE is a GIS tool that can be used to develop regionally relevant ecosystem services measurement and assessment programs and that can be used to assist in implementing efficient and effective decision-making by local and regional regulatory, mitigation, enforcement programs. The ECOSERVE method protocol is applicable elsewhere southwest Florida in

the southeastern United States, and around the Gulf of Mexico, provided that the ecosystem services values are recalibrated to the specific conditions of the subject watershed.

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