Estimating the Cumulative Ecological Effect of Local Scale Landscape Changes in South Florida

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Abstract Ecosystem restoration in south Florida is a state and national priority centered on the Everglades wetlands. However, urban development pressures affect the restoration potential and remaining habitat functions of the natural undeveloped areas. Land use (LU) planning often focuses at the local level, but a better understanding of the cumulative effects of small projects at the landscape level is needed to support ecosystem restoration and preservation. The South Florida Ecosystem Portfolio Model (SFL EPM) is a regional LU planning tool developed to help stakeholders visualize LU scenario evaluation and improve communication about regional effects of LU decisions. One component of the SFL EPM is ecological value (EV), which is evaluated through modeled ecological criteria related to ecosystem services using metrics for (1) biodiversity potential, (2) threatened and endangered species, (3) rare and unique habitats, (4) landscape pattern and fragmentation, (5) water quality buffer potential, and (6) ecological restoration potential. In this article, we demonstrate the calculation of EV using two case studies: (1) assessing altered EV in the Biscayne Gateway area by comparing 2004 LU to potential LU in 2025 and 2050, and (2) the cumulative impact of adding limestone mines south of Miami. Our analyses spatially convey changing regional EV resulting from conversion of local natural and agricultural areas to urban, industrial, or extractive use. Different simulated local LU scenarios may result in different alterations in calculated regional EV. These case studies demonstrate methods that may facilitate evaluation of potential future LU patterns and incorporate EV into decision making.

Keywords Ecosystem services · Ecological value · South Miami-Dade watershed study and plan · GIS · Florida Everglades · Model · Land use planning

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Introduction

The Florida Everglades are the target of a challenging multi-decadal state and national restoration effort to reverse the decline of the ecosystem bordered by growing human populations and conflicting water uses (NAS 2008). Miami-Dade County in south Florida is characterized by a diverse and growing human population directly adjacent to the Everglades wetland ecosystem (Rappaport 2007; MDCPZ 2008). Continued widespread conversion of agricultural lands to urban and suburban development is expected

(Zwick and Carr 2006) and will have significant regional implications for the ecological functions of the remaining undeveloped lands in the County, the ecological health of Everglades and Biscayne National Parks, and the well-being of Miami-Dade County residents (Stohlgren and others 1998). Population growth, infrastructure development, land conversion, water withdrawal, eutrophication and pollution, habitat fragmentation, and loss of wildlife corridors are primary drivers of natural ecosystem degradation (Marella 1992; Peck 1998; Solecki and others 1999; Cantillo and others 2000; Tong and Chen 2002; MEA 2005; Ye and others 2009). A priority when making land use decisions that directly or indirectly influence wetlands is to ensure that information about the range of benefits and values provided by different wetland ecosystem services is considered (MEA 2005). Wetland ecosystems provide numerous services that contribute to human well-being including biodiversity support, habitat provision, water quality improvement (nutrient and sediment removal and retention), flood mitigation, groundwater discharge and recharge, recreation and tourism, coastal protection, and global change mitigation (Johnston 1991; Walbridge 1993; Zedler 2003; MEA 2005).

Land use decision making is often done at the local level (Allan and others 1997; Theobald and others 2000; Brody 2008). It can be difficult to demonstrate that while each single land use change may result in a negligible impact, the accumulation of these individual changes over time and within a region may constitute a major impact (Theobald and others 1997; Brody 2008). Many of the effects of development on ecological processes including biodiversity, landscape fragmentation and integrity, surface water flow, and habitat provision for native species, may best be estimated at a regional scale (Theobald and others 1997; Stohlgren and others 1998; Nitschke 2008). In addition, the cumulative effects of development can affect regional flood control requirements, flood and storm surge risk, and runoff and water contaminant fluxes.

Many resource managers and land use planners realize that evaluating land use conversions on a parcel basis leads to a limited view of the regional effects but they often lack the information to influence or even consider regional events (Marsh and Lallas 1995; Allan and others 1997; Theobald and others 2000). The ecosystem portfolio model (EPM) is a regional land use planning tool developed to facilitate generation, visualization, and refinement of land use scenarios and to assist regional ecological and community quality-of-life assessments of these scenarios (Labiosa and others 2009).

The South Florida Ecosystem Portfolio Model (SFL EPM)

The South Florida Ecosystem Portfolio Model (SFL EPM) is a web-enabled, Geographic Information System-based

regional land use decision support tool. At the SFL EPM homepage (http://lcat.usgs.gov/sflorida/), the user can click the ? icon to find help screens providing a model overview, a description of the layers, a description of the toolbar, instructions on running the EPM, and help with use of the user-defined land use/land cover (LULC) option. In addition, the user can find a link to the scientific investigations report, where a detailed description of the model development may be found (Labiosa and others 2009; the direct link to the report is http://pubs.usgs.gov/sir/2009/5181/).

The SFL EPM is comprised of three categories of models that estimate (1) ecological value, (2) economic valuation, and (3) community quality-of-life. Each category generates maps to help visualize the effects of land use changes and may be used separately or comparatively in tradeoff analyses. A primary goal during the development of the SFL EPM was to allow the user as much flexibility as possible to better reflect the diverse priorities and management objectives of those with land use interests in south Florida. Therefore, SFL EPM users may choose to use model default weights, or assign their own relative weights to the modeled ecological value criteria, and may interactively modify the land use classifications to simulate and compare future potential land use scenarios. Further, the SFL EPM is designed to be updated as new data are available or models are improved.

The case studies in this paper demonstrate the calculation and potential use for decision making of the ecological value metrics only, which are described in the next section. The economic valuation category is a real estate market-based land price model that relies on hedonic pricing functions to estimate land parcel prices in Miami-Dade County as a function of land use/cover patterns (Labiosa and others 2009; Bernknopf and others 2010). The community quality of life category is a set of socioeconomic indicators and metrics that are sensitive to land use/cover changes such housing affordability and densities, commute times, flood or storm surge hazards, hurricane evacuation times, green space extent and placement, and indices of community well-being, character, and amenities. The economic valuation and community quality-of-life categories are explored in other venues (Labiosa and others 2009; http://lcat.usgs.gov/sflorida/).

The Ecological Value (EV) Model of the SFL EPM

The ecological value (EV) model, a component of the SFL EPM, is designed to evaluate land use scenarios with respect to modeled ecological criteria related to ecosystem services. The EV model provides a valuation of ecosystem services without monetization. The EV component provides an important perspective on ecosystem services-related values,

in addition to the hedonic land price model, which monetizes some aspects of ecosystem services-related values, but which misses other non-market aspects of value (National Research Council 1994; Goulder and Kennedy 1997; Wilson and Howarth 2002; Bernknopf and others 2010).

The six criteria used to define EV in this work (Table 1) are based on existing models or accepted methods and were developed in collaboration with scientists and managers at the Everglades National Park, Biscayne National Park, U.S. Geological Survey (USGS), and U.S. Fish and Wildlife Service to address conservation, preservation, and resource management objectives and mandates. Each criterion is scored from 0 to 10 to reflect potential relative ecological and environmental responses to land use/cover for individual 30 × 30 m cells as determined by a model and criterion-specific characteristics (Table 1). The 30 × 30 m grid cell size was chosen due to the spatial scale of the input data used in the model. This scale may limit model applicability to small, local level land use decision making, but the EPM is intended to help visualize, refine, and inform regional level ecological assessments of land use scenarios. Scores may be displayed either by using individual value maps for each of the six criterions, or as an aggregated 'ecological value map' after the user assigns

criteria weights to specify the relative importance of each criterion (Eq. 1). Sensitivity analyses on criteria weights and model parameters can address questions about the degree to which user preferences affect value maps. Multi-attribute utility theory is a structured methodology designed to handle the tradeoffs among multiple objectives and is used here to allow direct comparison of criteria scores and allow aggregation of individual criterion scores into an aggregate ecological value score (see Labiosa and others 2009). Through the combined use of ecological scoring models and multi-attribute utility models, EV integrates the ecological sciences with the decision sciences to yield a land use/cover evaluation tool that can be used to link changes in different land use scenarios to calculated alterations in EV.

Aggregate 'Ecological Value' for each cell

$$= \sum (\text{weight}) \times (\text{criteria score})/\text{total weight} \qquad (1)$$

EV Criterion 1: Biodiversity Potential (BP)

Biodiversity in sensitive natural areas such as wetlands, is substantially affected by human land use, including habitat destruction, habitat fragmentation, and degradation of

Table 1 The six criteria used to define Ecological Value (EV). Table adapted from Labiosa and others (2009)

Criterion	Model or method	Description
Biodiversity potential (BP)	Florida GAP analysis project (Pearlstine and others 2002)	Habitat preference models for all the terrestrial mammal, bird, amphibian, and reptile species in Florida. Uses land cover classes[a] at 30 × 30 m scale
Threatened and endangered species (TES)	Multi-species recovery plan (MSRP); US Fish and Wildlife Service	Habitat preference models focusing on 22 T&E species. Uses land cover classes[a] at 30 × 30 m scale
Rare and unique habitats (RUH)	Digital maps of rare and unique habitats; Florida natural areas inventory (FNAI)	Uses land cover classes[a] at 30 × 30 m scale
Landscape pattern and fragmentation (LPF)	FRAGSTATS; University of Massachusetts, Amherst (McGarigal and Marks 1995)	Computes landscape metrics based on 30 × 30 m cell classes[b] within a 1,200 m moving window
Water quality buffer potential (WQP)	Attribute and distance ranking model based on land use categories and pollutant loading data (Harper 1994, Adamus and Bergman 1995)	Scores based on adjacency to surface waters, land use, and contaminant loading rates. Uses parcel location relative to water and land cover classes[c] at 30 × 30 m scale
Ecological restoration potential (ERP)	Attribute and distance ranking model; US geological survey and Everglades national park	Scores based on proximity to natural areas, canals, and wellfields, historical habitat and land cover, and BP, TES, RUH, and LPF scores given restoration
		Uses parcel location, land cover classes[a] at 30 × 30 m scale, and historic land cover[d]

[a] Classes based on the Florida Land Use, Land Cover Classification System (FLUCCS, http://www.dot.state.fl.us/surveyingandmapping/manuals/fluccmanual.pdf)

[b] FLUCCS land cover classes reclassified into either "hospitable" (habitat or traversable land cover) or "non-hospitable" (not habitat and non-traversable) classes

[c] Re-classified land uses based on Harper (1994) and Adamus and Bergman (1995)

[d] From 1943 historic vegetation land cover map, digitized from original South Florida Water Management District paper map by John H. Davis, Jr. of the Florida Geological Survey

supporting environmental conditions (McKinney 2002; Eppink and others 2004). The purpose of the biodiversity potential (BP) criterion is to estimate the impacts of land use/land cover change on potential general wildlife habitat, an indicator of the ability of a landscape to support biodiversity. A common measure of biodiversity is species richness, which is a count of how many different species are present at a site. The BP criterion estimates potential biodiversity based on whether or not the observed, or EPM user assigned, land cover type for a site is potential habitat for a set of reference species (Hildebrand and Cannon 1993; Morris and Therivel 1995). These determinations are based on the Florida Gap Analysis Project model (FL GAP) (Pearlstine and others 2002; http://www.wec.ufl.edu/coop/GAP/); updated using the 2004–2005 Florida Land Use, Land Cover Classification System (FLUCCS) (http://my.sfwmd.gov/gisapps/sfwmdxwebdc/dataview.asp?query=unq_id=1813). The GAP model provides an assessment of the potential habitat of all terrestrial species of mammals, birds, amphibians, and reptiles in Florida (Pearlstine and others 2002). The score for the BP criterion links the potential presence of a native species to land cover type using the FLUCCS land use code.

EV Criterion 2: Threatened and Endangered Species (TES)

The threatened and endangered species (TES) criterion estimates potential TES species richness to provide the ability to prioritize specific locations and habitat types for the protection of TES. Potential TES species richness is estimated using the U.S. Fish and Wildlife Service's Multi-Species Recovery Project (MSRP) model, which expands on the FL GAP models for 22 terrestrial vertebrate south Florida species listed under the Endangered Species Act (Table 2;

(http://www.fws.gov/verobeach/index.cfm?Method=programs&NavProgramCategoryID=3&programID=107&ProgramCategoryID=3). As with the GAP model, the MSRP has been modified to use the 2004-2005 FLUCCS. The TES criterion scores a location (cell) based on whether its assigned FLUCCS land use code corresponds to preferred, suitable, or unsuitable habitat by species. The TES utility model is non-linear and tends to plateau when the land cover provides suitable or preferred habitat for a relatively small number of TES (as low as 3–10); therefore, the hypothetical maximum richness scores do not require all 22 species to be potentially present in a given location (Labiosa and others 2009).

EV Criterion 3: Rare and Unique Habitats (RUH)

The purpose of the rare and unique habitats (RUH) criterion is to emphasize the importance of these habitats, as identified by the Florida Natural Areas Inventory (FNAI), a Florida state conservation prioritization system (http://www.fnai.org/). The FNAI maintains a database of occurrences of ~1,000 rare plant/animal species and 70 natural community types. For each element (a species or a community), FNAI assigns a Global Rank (GRANK) and a State Rank (SRANK) to indicate the overall rarity of the species or community on a global and statewide basis. The GRANK is assigned by Nature Serve and the Natural Heritage Program network (of which FNAI is a participant), and refers to the status of the species worldwide (five ranks ranging from imperiled to secure). Rank is based on distributions of occurrence, distributions of abundance, range, number of protected occurrences, relative threat of destruction, and ecological fragility. The RUH criterion scores are obtained by overlaying the FNAI Rare Species Habitat Conservation Priorities map over the cell grid and transferring direct or estimated polygon scores to the grid

Table 2 Florida species listed under the Endangered Species Act and considered by the Threatened and Endangered Species (TES) criterion

American Crocodile (*Crocodylus acutus*)	Key Deer (*Odocoileus virginianus clavium*)
Atlantic Salt Marsh Snake (*Nerodia clarkii taeniata*)	Key Largo Cotton Mouse (*Peromyscus gossypinus allapaticola*)
Audobon's Crested Caracara (*Polyborus plancus audubonii*)	Key Largo Woodrat (*Neotoma floridana smalli*)
Bald Eagle (*Haliaeetus leucocephalus*)	Lower Keys Marsh Rabbit (*Sylvilagus palustris hefneri*)
Bluetail Mole Skink (*Eumeces egregius lividus*)	Piping Plover (*Charadrius melodus*)
Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*)	Red Cockaded Woodpecker (*Picoides borealis*)
Eastern Indigo Snake (*Drymarchon corais couperi*)	Roseate Tern (*Sterna dougallii dougallii*)
Everglades Snail Kite (*Rostrhamus sociabilis plumbeus*)	Sand Skink (*Neoseps reynoldsi*)
Florida Panther (*Puma [Felis] concolor coryi*)	Silver Rice Rat (*Oryzomys palustris*)
Florida Scrub Jay (*Aphelocoma coerulescens*)	Southeastern Beach Mouse (*Peromyscus polionotus niveiventris*)
Florida Grasshopper Sparrow (*Ammodramus savannarum floridanus*)	Wood Stork (*Mycteria americana*)

cells. The protection of RUH can overlap with the protection of TES (criterion 2) and BP (criterion 1).

EV Criterion 4: Landscape Patterns and Fragmentation (LPF)

Landscape connectivity and pattern is important for species and gene movement, biodiversity conservation, resource availability, metapopulation dynamics, and other ecological processes (Taylor and others 1993). The landscape patterns and fragmentation criterion is an aggregate of four metrics focusing on aspects of the ability of a regional landscape to sustain these functions (Table 3). The four landscape patterns and fragmentation metrics are adapted from the public domain FRAGSTATS package, maintained by the University of Massachusetts Amherst (http://www.umass.edu/landeco/research/fragstats/fragstats.html). FRAGSTATS is a spatial pattern analysis program with a collection of landscape metrics used to measure landscape composition and configuration (McGarigal and Marks 1995).

Many common landscape ecological indices provide redundant information about spatial pattern, are scale sensitive, do not have clearly demonstrated relations to ecological responses, and may not provide a consistent response in different landscapes (Tischendorf 2001). For these reasons, representative FRAGSTATS metrics were tested using a two-class system (habitat and nonhabitat) at six diverse southeast and southwest Florida study sites, and analyzed for metric independence and sensitivity to land use change in a 1200 m radius moving window analysis (see Labiosa and others 2009). This analysis identified the four metrics listed in Table 3 that were adapted to define landscape patterns and fragmentation (COH and HNSUM are modified from the FRAGSTATS metrics of Patch Cohesion Index and Mean Euclidean Nearest Neighbor Distance as outlined in Table 3). The results from the metrics in Table 3 are combined in a multi-attribute utility function using user-entered weight and scaling parameters (Labiosa and others 2009).

EV Criterion 5: Water Quality Buffer Potential (WQP)

Urban and agricultural environments are potential sources of excess nutrients (i.e., nitrogen and phosphorus) and sediment, and surface water pollutant transport to downstream ecosystems is facilitated by proximity to water conduits (Hopkinson and Day 1980; Johnston 1991; Carpenter and others 1998; Reinelt and others 1998). The water quality buffer potential (WQP) criterion examines land use adjacent to and near surface water conduits (often canals in Miami-Dade County) and considers the potential effects of different land uses in this area on downstream water quality. In general, a score is assigned based on land use/cover and distance for each cell in a defined buffer zone around surface water features (e.g., canals, lakes, wetlands) separately for nitrogen, phosphorus, and sediment. The scores for the three pollutants are weighted by the user and combined with weighting to provide the overall score to reflect the importance of each contaminant in terms of management objectives.

A buffer zone around surface water bodies (i.e., canals, lakes, wetlands) was delineated using the USGS National Hydrography dataset (http://nhd.usgs.gov/). Buffers were conservatively defined at 180 m based on Miami Conservancy estimates for riparian protection http://www.miamiconservancy.org/flood/pdfs/riparian_buffers.pdf). Six 30 × 30 m cells were used to account for the 180 m buffer and the cell containing the canal or the edge of the water body. A linear attenuation factor accounted for the distance of a cell to the closest surface water conduit. Thus, the cell closest to the water body has an attenuation factor of one and at the sixth cell, the attenuation factor has been reduced to 0.167. Cells outside of the 180 m buffer received an attenuation factor of zero and are thus not considered in the WQP criterion.

The FLUCCS codes were reclassified into 14 categories as shown in Table 4 (following Harper 1994, Adamus and Bergman 1995). The reclassified FLUCCS codes were then related to mean pollutant concentrations commonly found in runoff in south Florida based on different land uses

Table 3 Metrics used in the landscape patterns and fragmentation criterion

Metric	Type	Definition
Total class area (CA)	Area/density/edge	CA is a measure of landscape composition; specifically, how much of the landscape is comprised of a particular type. CA approaches zero as the patch type becomes increasingly rare
Patch cohesion (COH)	Connectivity	COH measures the physical connectedness of a patch type and increases as the patch type becomes more clumped or aggregated. COH is not used (i.e., assigned a zero weight) if the 1200 m moving window around a study cell contains more than 60% habitat (Keitt and others 1997)
Core area distribution (CORE)	Core area	CORE represents the area greater than the specified edge depth distance from the perimeter. CORE ≥ 0, without limit
Habitat neighbor sum (HNSUM)	Isolation/proximity	HNSUM is the sum of cells adjacent to a given cell that are habitat, plus the cell itself if it is habitat

Table 4 Reclassification of the FLUCCS codes for use in the water quality buffer potential (WQP) criterion model (following Harper 1994; Adamus and Bergman 1995)

Class	Definition
Low density residential	Less than or equal to one dwelling unit per acre
Medium density residential	More than one and less than or equal to five dwelling units per acre
High density residential	More than five dwelling units per acre
Low intensity commercial	Institutional, governmental, professional offices
High intensity commercial	Shopping areas, urban centers
Industrial	Industrial
Agriculture—pasture	Improved and unimproved pastures
Agriculture—crops	Row crops, field crops, mixed crops
Agriculture—citrus	Citrus
Agriculture—other	Other agriculture
Mining	Mining
recreation, open space, range	Recreation, open space, rangeland
Wetland	Wetlands
Open water/lake	Water bodies

Table 5 Relative mean pollutant concentrations (mg/l) commonly found in runoff in South Florida and the normalized pollutant values used for the water quality buffer potential (WQP) criterion (following Harper 1994; Adamus and Bergman 1995)

Class	Pollutant (mg/l)			Normalized value		
	TN	TP	SS	TN	TP	SS
Low density residential	1.77	0.18	19.1	1.01	0.78	0.49
Medium density residential	2.29	0.30	27.0	1.90	1.52	0.73
High density residential	2.42	0.49	71.7	2.13	2.70	2.08
Low intensity commercial	1.18	0.15	81.0	0.00	0.60	2.37
High intensity commercial	2.83	0.43	94.3	2.83	2.33	2.77
Industrial	1.79	0.31	93.9	1.05	1.59	2.76
Agriculture—pasture	2.48	0.476	55.3	2.23	2.61	1.59
Agriculture—crops	2.68	0.562	55.3	2.57	3.14	1.59
Agriculture—citrus	2.05	0.140	55.3	1.49	0.54	1.59
Agriculture—other	2.32	0.344	55.3	1.96	1.79	1.59
Mining	1.18	0.15	93.9	0.00	0.60	2.76
Recreation, open space, range	1.25	0.053	11.1	0.12	0.00	0.24
Wetland	1.60	0.190	10.2	0.72	0.84	0.22
Open water/lake	1.25	0.11	3.1	0.12	0.35	0.00
standard deviation	0.582749	0.162144	32.92377			

(Harper 1994, Adamus and Bergman 1995) (Table 5). We normalized each of the mean pollutant concentrations to relative values so that we could compare the three pollutants together in the WQP criterion. For each pollutant and land use, a normalized value is derived by subtracting the concentration value from the lowest concentration value, and then dividing by the standard deviation of all the values for that pollutant (Table 5). Scoring for the WQP criterion is done for each cell, "k", in the buffer zone individually for total nitrogen (TN), total phosphorus (TP) and suspended sediment (SS). The final score is a user-defined weighted average of the three scores for TN, TP, and SS, defined by Eq. 2

$$\text{Score}_k = \frac{w_D^* \sum_1^J \left(w_j * N_{j,l} \right)}{\sum_1^J w_j} \qquad (2)$$

where w_D is the attenuation factor based on distance from canal, w_j is the user-adjusted weight for contaminant "j", $j \in \{TN, TP, SS\}$, and $N_{j,l}$ is a normalized concentration value for contaminant "j" and land use type "l".

EV Criterion 6: Ecological Restoration Potential (ERP)

The purpose of the ecological restoration potential (ERP) criterion is to identify areas that may have low existing

ecological value, but that historically provided high ecological value and still possess characteristics indicative of potential successful restoration. Therefore, the focus is on the potential to restore currently disturbed environments, which would score lower on the other EV criteria, while also accounting for proximity to natural land use/land cover, canals, and wellfield protection zones. The ERP criterion uses only areas where restoration is feasible as identified using the current FLUCCS classes for vacant, agriculture, open urban, and natural areas dominated by invasive species. In these areas, the restoration potential is defined relative to a 1943 (pre-extensive drainage) historic vegetation map (30 m spatial resolution) to determine the land cover to which the current cell could hypothetically be restored. To calculate the ERP score, the existing land cover classes are reset to the historical land-cover classes and evaluated using the EV criteria as defined above. These scores are assigned user-defined weights and used with terms related to proximity to currently natural areas, canals, and wellfield-protection zones (see Labiosa and others 2009).

Case Studies

We used the SFL EPM to calculate EV using two case studies: (1) assessing changes in EV in the Biscayne

Gateway area given potential future land use scenarios, and (2) the cumulative impact of adding limestone mine footprints south of Miami (Fig. 1).

Case Study 1: The Effect of Potential Future Land Use Changes on Ecological Value

The population of Miami-Dade County is expected to continue to grow in the future driving further area land use change (Miami-Dade.gov (2010); Florida Housing Data Clearinghouse (2010)). The South Miami-Dade Watershed Study and Plan (http://southmiamidadewatershed.net/) was conducted as a long-term planning and water resources study of the south Miami-Dade Watershed, a 961 km² area in the southern part of the county. The study and plan was a collaborative effort by Miami-Dade County, the South Florida Regional Planning Council, the South Florida Water Management District, and the consultant Keith and Schnars, P.A., with refinement from local experts and public involvement. As part of that work, preferred land use scenarios were developed for the years 2025 and 2050 that are based on sustainability and smart growth as defined by principles focusing on compact, transit-oriented, walkable, and bicycle-friendly mixed-use development (http://southmiamidadewatershed.net/). The case study used in this paper uses a section of the 2025 and 2050 preferred land use scenarios as an example land use change dataset to

Fig. 1 Study area map. Miami-Dade County is shown by the *solid white line*, and Everglades and Biscayne National Parks are shown with the *white dotted lines*. In between the National Parks are the two case study areas used in this paper delineated in the *black boxes*. The Biscayne Gateway case study area is the *smaller area* and the limestone mine study area is the *larger area*. The two case study areas overlap slightly
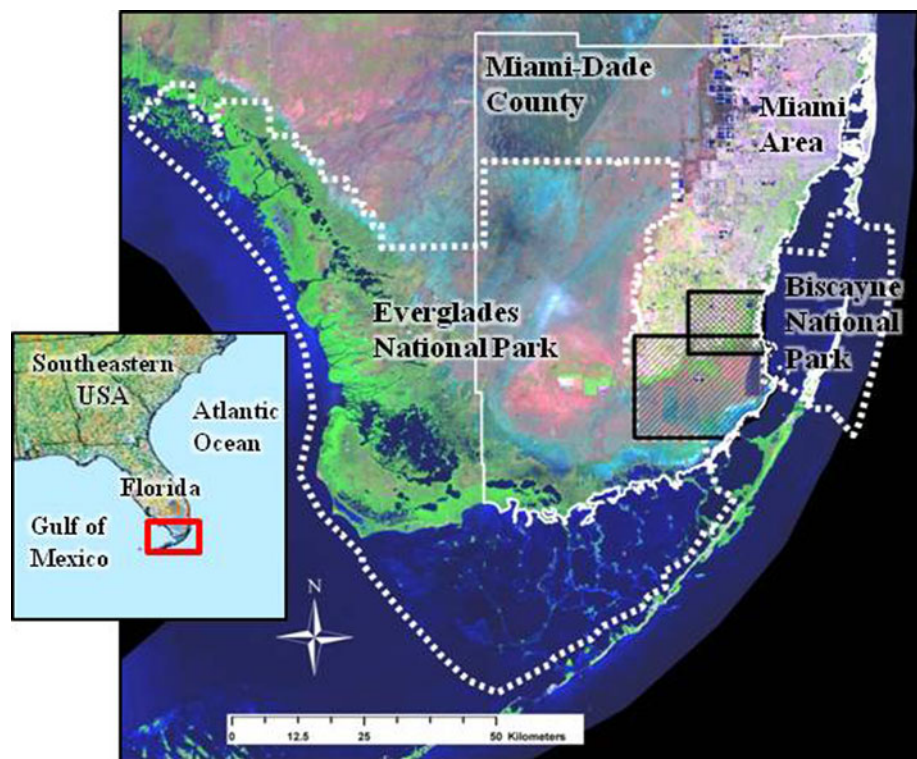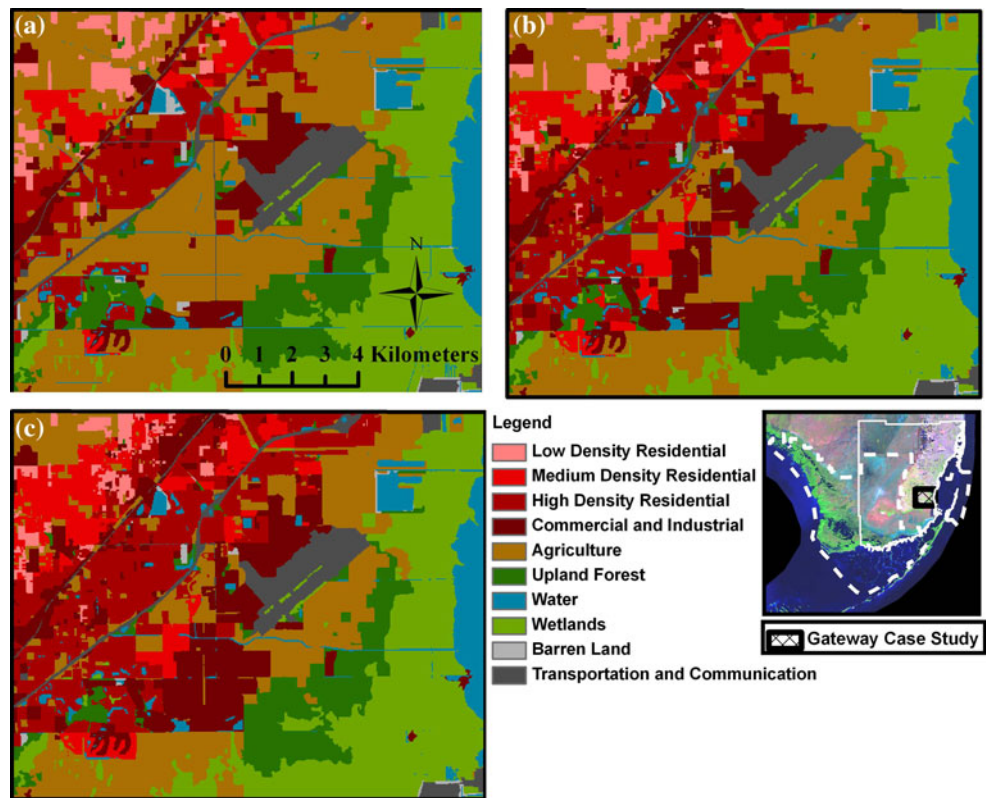
Fig. 2 The Biscayne National Park (BNP) Gateway area (shown in *inset*) with (**a**) 2004 Florida Land Use, Land Cover Classification System (FLUCCS) data, (**b**) the 2025 Watershed Study Preferred Scenario, and (**c**) the 2050 Watershed Study Preferred Scenario

compare to 2004 land use data. We chose these datasets given their availability, and do not imply support or criticism of the South Miami-Dade Watershed Plan.

Visitors to Biscayne National Park (BNP) travel through what we refer to as the BNP Gateway area; delineated for the purposes of this case study as shown in Figs. 1 and 2. The Gateway includes agricultural lands, natural areas, and residential and commercial development, and is an important area for the maintenance of hydrology, ecosystem services, and habitat and corridor connectivity between Everglades and Biscayne National Parks. This area was projected to receive significant changes under the 2025 and 2050 Watershed Study Preferred Scenarios including a decrease in agriculture (33% in 2025 and 77% in 2050) and an increase in medium and high density residential and commercial and industrial land uses (35% in 2025 and 48% in 2025; Fig. 2).

This case study examined how EV (Eq. 1) changed in the BNP Gateway area given the land use changes proposed by the 2025 and 2050 Watershed Study Preferred Scenarios in comparison to the 2004 Florida Land Use, Land Cover Classification System (FLUCCS) data (Fig. 2). Analyses were run using model EV default values and uploading the future land use scenarios (see http://lcat. usgs.gov/sflorida/ for details on uploading scenarios). EV values and weights other than the defaults should be used based on management preferences and mandates.
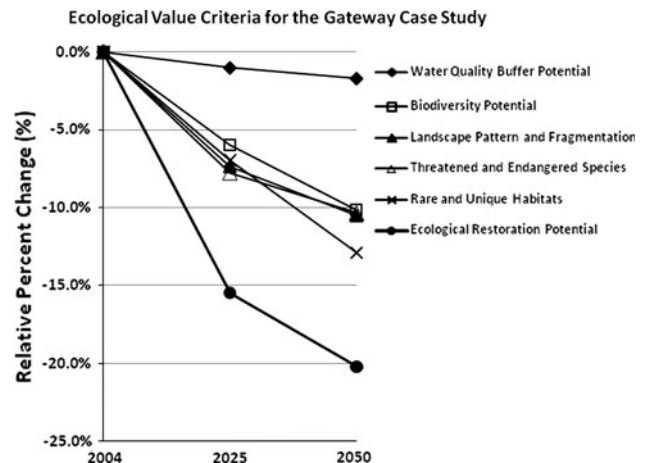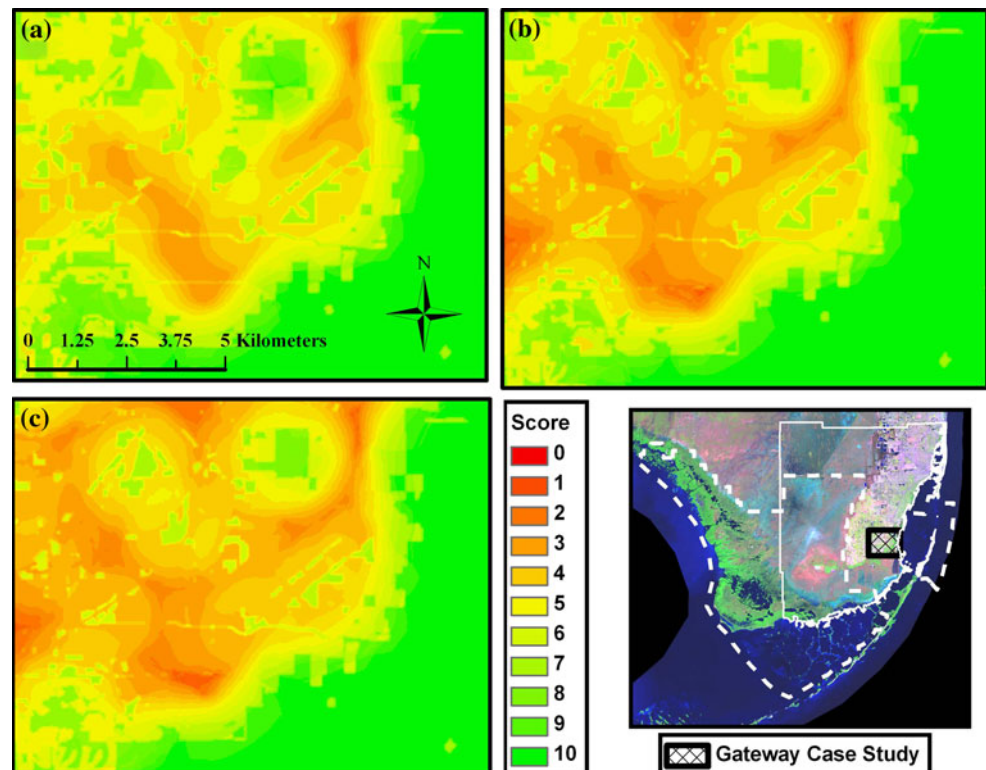

Fig. 3 The relative percent change of the mean score for each individual criterion as prospective land use/cover changes in the Gateway study area between 2004, 2025, and 2050

The projected land use conversion in the Gateway study area between 2004, 2025, and 2050 (Fig. 2) resulted in decreasing average criteria scores for each of the six individual EV criterion as determined by the criterion-specific model and characteristics (Table 1; Fig. 3). The values calculated for the six EV criteria reflect the potential ecological response to land use/cover and are unitless, but may individually be relatively explored. In this case study, the water quality buffer criterion experienced a minor

Fig. 4 A comparison of the raster grid of the scores for the landscape patterns and fragmentation index for the Biscayne National Park (BNP) Gateway area (shown in *inset*) using (**a**) 2004 Florida Land Use, Land Cover Classification System (FLUCCS), (**b**) the 2025 Watershed Study Preferred Scenario, and (**c**) the 2050 Watershed Study Preferred Scenario

decrease as land use changed (relative percent change of 1.0% in 2025 and 1.7% in 2050; Fig. 3). Urban environments are known sources of nitrogen, phosphorus, and sediment that may be detrimental to water quality; however much of the altered landscape had previously been in agricultural land use—also a well known source of nitrogen, phosphorus, and sediment (Hopkinson and Day 1980; Carpenter and others 1998; Reinelt and others 1998). The changing land use also negatively affected habitat to support biodiversity (relative percent change of 6.0% in 2025 and 10.2% in 2050), threatened and endangered species (relative percent change of 7.8% in 2025 and 10.3% in 2050), and available rare and unique habitat (relative percent change of 7.0% in 2025 and 12.9% in 2050; Fig. 3). Figure 4 shows the SFL EPM output for the landscape pattern and fragmentation index. Green areas have the highest value and red have the lowest. Decreasing scores were found as overall landscape fragmentation and connectivity values decreased as the land use shifted from agricultural to more residential and commercial development (Figs. 2, 3; relative percent change of 7.4% in 2025 and 10.5% in 2050). The ecological restoration potential criterion focuses on the potential to restore currently disturbed environments, and assumes that urban landscapes do not have significant restoration potential due to the intensity of landscape alteration and the economic investment in urban infrastructure. Therefore, as land use changed from areas with restoration potential to areas without notable

restoration potential, this metric also decreased (relative percent change of 15.5% in 2025 and 20.2% in 2050; Fig. 3).

To estimate the cumulative regional ecological effects of development, we used the SFL EPM to calculate EV (the aggregate of the six criteria, Eq. 1) as potential land use changed. Figure 5 shows the EV scores for the 2004, 2025, and 2050 comparison. For this case study, decreases were observed in the amounts of low to moderate EV scores (3–4 and 5–6) and increases were found for the lowest EV classes (0–2). The study area grid cells with the highest EV (7–9) appear to remain steady. Although ecological value scores may range from 0 to 10, the highest score in this scenario was a nine.

These results may be indicative of the goals driving the development of the datasets we used for this case study; the preferred land use scenarios produced as part of The South Miami-Dade Watershed Study and Plan (http://southmiamidadewatershed.net/). This preferred land use scenario recognized that the human population in the area was expected to nearly double by 2050, and was designed to evaluate the impacts of that population growth and explore how those impacts might be mitigated. In this small part of the area analyzed by the South Miami-Dade Watershed Study and Plan, the plan developers seemed to concentrate the infrastructure needed to support that increase in population in areas with low to moderate EV scores (primarily agricultural lands), thereby transitioning some of those
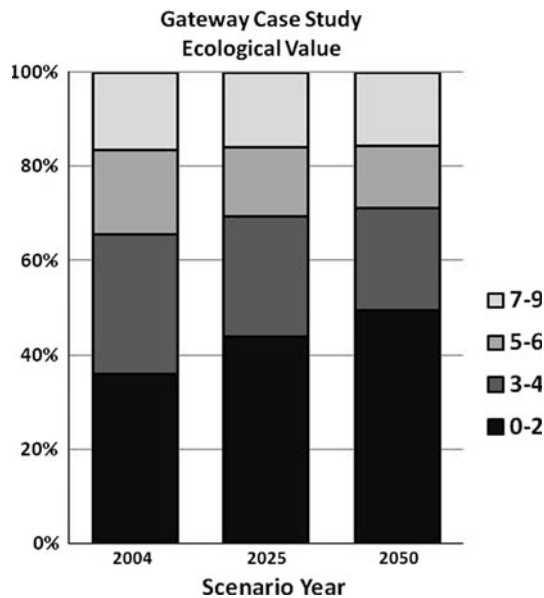
Fig. 5 Aggregate Ecological Value (EV) scores for the 2004, 2025, and 2050 land use scenarios in the Biscayne National Park (BNP) Gateway case study

areas to the lowest EV classes (Fig. 5). Areas with the highest EV scores (primarily representing natural areas and habitat) did not appear to be converted in this scenario, potentially allowing contiguous natural areas to remain. This case study outlined the type of analysis that might be done for a planning group with a mandate to respond to exploding population projections with smart growth patterns, and would likely be done in a comparison to other land use scenarios under consideration for the area.

South Miami-Dade County land use will inevitably change and population will likely increase considerably between now and the year 2050, exasperating existing issues of livability and environmental sustainability. The Watershed Study Preferred Scenario (http://southmiamid adewatershed.net/) used in this case study provided an option to help address issues of smart growth and sustainability, but even this proposed future land use scenario resulted in a decrease in individual EV criteria scores and in regional cumulative EV in the BNP Gateway. The ability to visualize and consider the cumulative effect of changing land use patterns is valuable to understanding and communicating the regional effects of land use changes. Each single land use change may result in a negligible impact, but the accumulation of individual changes over time and within a region may constitute a major impact.

Case Study 2: The Cumulative Impact of Limestone Mine Footprints

Mining in south Florida provides limestone and sand, key ingredients for the concrete that is the basis for most local

infrastructure. However, mining is also recognized to have several negative environmental impacts including disruption of sheet flow and the creation of large areas of deep water habitat that normally do not occur in south Florida, disturbing habitat for native species. The cumulative ecological impacts of multiple mining projects need to be understood at the regional scale.

The land bridge is an area of primarily open or agricultural lands between Everglades and Biscayne National Parks (Figs. 1, 6). This area is important for habitat and corridor connectivity between the Parks, and provides vital hydrologic and ecological services. The land bridge area also serves as a buffer between the highly urbanized areas and the protected park areas.

In this case study, we analyze the potential cumulative effects on EV of the conversion of natural areas in the land bridge to rock mining activities. To do this, we use representative areas that may or may not currently be under consideration for mining. In practice, the user would create a land use layer to reflect their specific land use management decisions to obtain the pertinent EV scores. This type of analysis is relevant to resource managers or decision makers considering the effects of changing land use on regional ecology or for planning the acquisition of selected areas for preservation or restoration.

This case study examined the potential cumulative impacts on regional EV if none, a few, or all of the ten areas shown in Fig. 6 are approved for future mining activities (potential mining areas in Fig. 6 were created solely for use in this analysis). Analyses were done using model default EV values and uploading each potential future mine land use scenario (that is, adding mines to the landscape two at a time; see http://lcat.usgs.gov/sflorida/ for details on uploading scenarios).

Addition of rock mine footprints to the natural land cover in this case study (Fig. 6) resulted in decreasing average criteria scores for each of the six individual EV criterion (Table 1; Fig. 7). The water quality buffer criterion showed a modest decrease as potential mines were added to the landscape because this criterion focuses on nitrogen, phosphorus, and sediment only, and the available model does not include mining as a source of those pollutants. Adding mines to the natural landscape caused a decrease in landscape pattern and fragmentation. We chose to keep our example simple by including only the mine footprints and not associated infrastructure such as new roads or buildings, which may have further disrupted landscape level connectivity. Habitat to support biodiversity and threatened and endangered species were affected by mine addition, but rare and unique habitat appeared to be the most affected, possibly due to inadvertent placement of prospective mines on these habitat types. Similar to the BNP Gateway case study, the ecological restoration

Fig. 6 The land bridge area (location shown as rock mine case study area in *inset*) showing the ten potential future mine footprints created for this case study. Note the existing mine in the zero added mine land cover data. To look at the cumulative effect as additional mines were added to the landscape, EV was calculated as mines were added two at a time as shown here
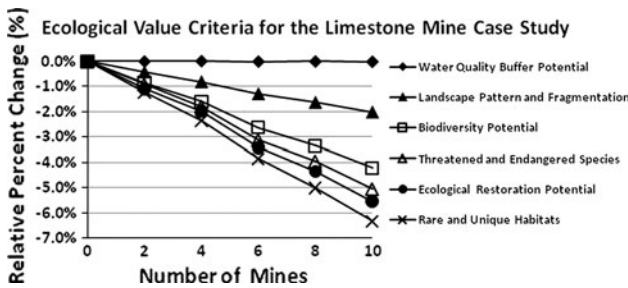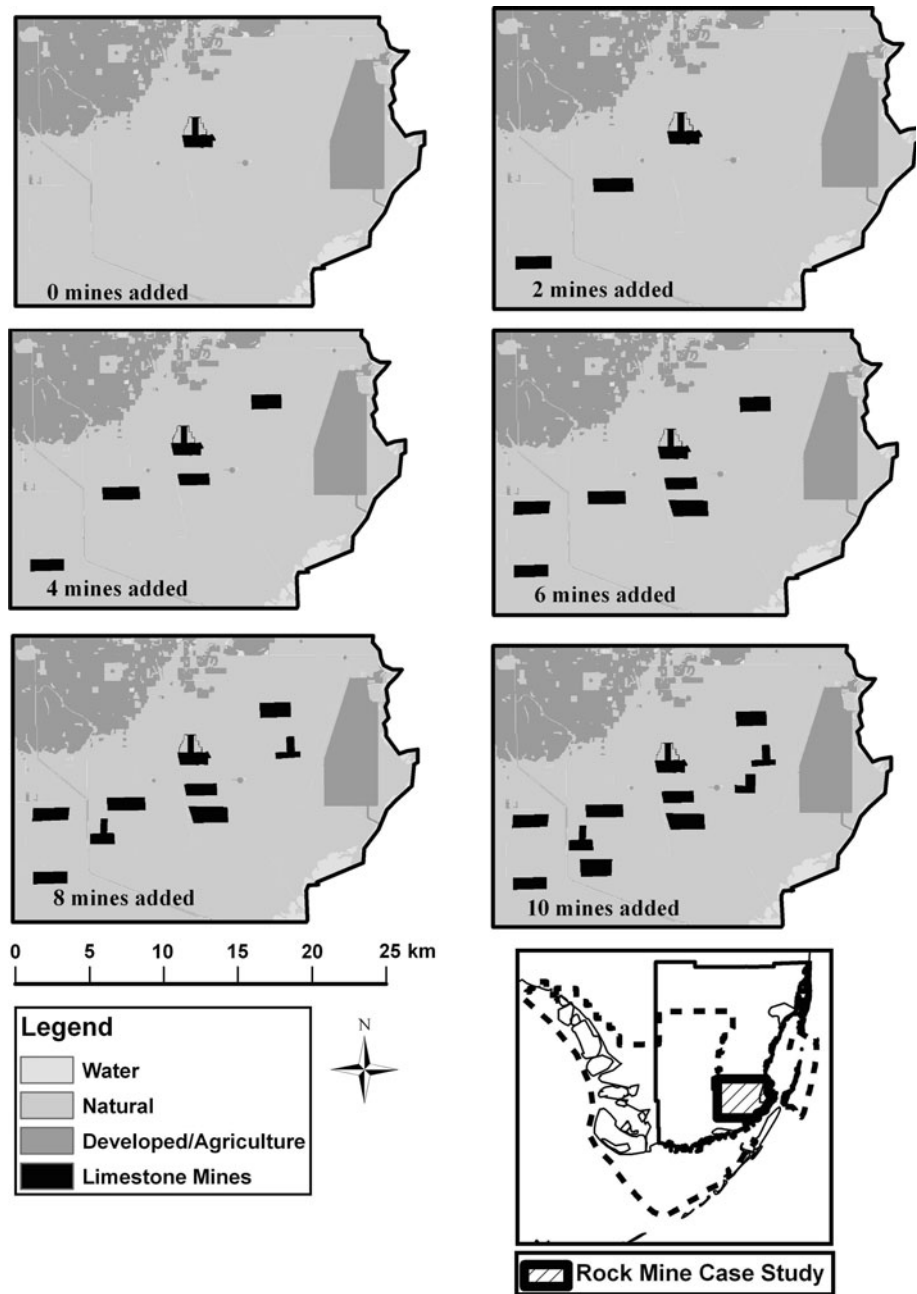

Fig. 7 The relative percent change of the mean score for each individual criterion as mines are added two at a time

potential criterion decreased primarily due to the change from natural areas and areas with restoration potential to areas that do not have significant potential for restoration (mine footprints create areas of deepwater habitat that do not normally occur in these areas).

Figure 8 shows the relative percent change in the number of study area grid cells with a given EV score as mines were added two at a time in comparison to the baseline landscape (2004 FLUCCS data). Altering the size, number, location, and order of land use changes (in this case mining) will have an effect on the resultant
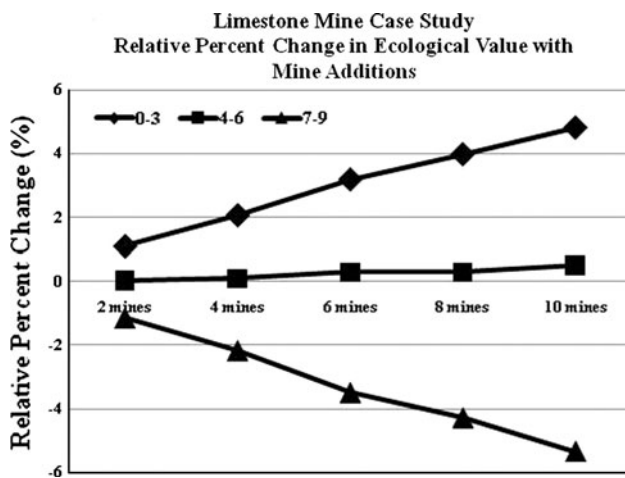
Fig. 8 The relative percent change in the number of raster grid cells in the study area with a given ecological value (EV) score as mines are added two at a time to the landscape (see also Fig. 6)

regional EV scores. Therefore, while you might expect an increasing cumulative effect as you continue to add mining footprints, it may not always be a linear relation depending on the land uses that are being replaced by the mines. In this case study, we placed mines on wetland areas therefore creating a situation with a large decrease in high EV and large increase in low EV. Different simulations of proposed large developments, restoration, or preservation scenarios will cause different increases and decreases in calculated individual criterion and aggregate EV scores.

Summary and Conclusions

The growing human population in south Florida depends on the multiple ecosystem services provided by wetlands and natural areas. However, urban development pressures threaten the restoration potential and the remaining habitat functions of the natural undeveloped, preserved, and agricultural areas in south Florida. Many important ecological processes including biodiversity, landscape fragmentation and integrity, water flow, and habitat provision for native species are best estimated at a regional scale (Theobald and others 1997; Stohlgren and others 1998; Nitschke 2008). By modeling changes in EV as impacted by land use change at a regional scale, we gain the ability to estimate cumulative impacts and better consider conservation, preservation and restoration efforts. The case studies used in this paper illustrate potential changes in EV from conversion of natural or agricultural areas to urban and suburban development or rock mining. The evaluation of these different land use scenarios was done

using modeled ecological criteria related to ecosystem services, and spatially explores decreases in habitat and restoration potential as an ecological consequence of regional land use/cover change.

The six SFL EPM EV criteria are designed to be improved and updated as new information or data become available. For the water quality buffer potential (WQP) criterion, new information could include updating the pollutant concentration values, incorporating more pollutants, including pollutant loads from more land cover types, and considering linking surface water and groundwater. In the future, we also plan to extend the application of the SFL EPM from Miami-Dade County to include other areas of interest in south Florida. Other changes to the SFL EPM include the addition of a community quality-of-life component that focuses on sea level rise vulnerability and the trade-offs between quality-of-life metrics (e.g., housing affordability and recreational opportunities) and sea level risk metrics (e.g., storm surge risk and salt water intrusion) for evaluating mitigation alternatives for sea level rise vulnerability. The SFL EPM approach is also currently being adapted for use in other urban–natural transition areas with land-use-related planning issues, including Puget Sound in Washington State and the Santa Cruz Watershed at the Arizona/Sonora, Mexico border.

The web-based SFL EPM and EV model can contribute to improved public understanding and awareness of the importance of protecting south Florida habitats and ecosystem functions and the inadvertent potential regional consequences associated with local level land use decisions. The SFL EPM is designed as a user-friendly web tool intended to link land use scenarios to changes in calculated ecological value, while allowing enough flexibility for users to either use available land use scenarios or design their own, impose their own prioritizations of criteria, and address different management objectives or policies while exploring alterations in EV. The goal of the overall EPM effort is to inform land use planning and facilitate land use scenario evaluation to help decision makers consider diverse ideas and visualize tradeoffs between human and ecological desires and needs.

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