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Articles

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Abstract

Reserve design is a process that can address ecological, social, and political factors to identify parcels of land needed to sustain wildlife populations and other natural resources. Acquisition of parcels for a large terrestrial reserve is difficult because it typically occurs over a long timeframe and thus invokes consideration of future conditions such as climate and urbanization changes. In central Florida, the U.S. government has authorized a new protected area, the Everglades Headwaters National Wildlife Refuge. The new refuge will host important threatened and endangered species and habitats, and will be located to allow for species adaptation from climate change impacts. For this study we combined habitat objectives defined by the U.S. Fish and Wildlife Service and projections from two urbanization models to provide guidance for Everglades Headwaters National Wildlife Refuge design. We used Marxan with Zones to find near-optimal solutions for protecting explicit amounts of five target habitats. We identified parcels for inclusion into the reserve design that the models allocated among two zones representing different methods of protection: fee-simple purchase (up to 20,234 ha authorized by the U.S. government), and conservation easement agreements (up to 40,469 ha authorized). As expected, for all scenarios we found an increase in costs as the proportion of fee-simple purchases was increased, reflecting the lesser cost of easements, but the number of parcels required for protection differed little among scenarios. The two urbanization models showed considerable agreement over which habitat patches they did not forecast to be developed, and some agreement over which parcels might be developed. The U.S. Fish and Wildlife Service may benefit from focusing on parcels that our analyses select frequently under both urban scenarios because these parcels are more likely to be in areas where there are fewer urbanization threats and a lower demand for land. The reserve designs we generated met U.S. Fish and Wildlife Service habitat goals within fee and easement zone restrictions, and we found reserve configurations that fell well below the mandated size limit.

Keywords: endangered; land acquisition; Marxan; optimization; reserve design

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Introduction

Habitat loss and subsequent declines in biodiversity result from stressors including land use change, resource consumption, climate change impacts, and invasive species (Butchart et al. 2010; Pereira et al. 2010; Martinuzzi et al. 2015). Globally, more than 50% of land previously in natural areas is now devoted to human use, and this trend continues in the 21st century (Ellis et al. 2010). Urbanization rates are also on the increase globally; without protection, less land remains for wildlife (Cohen 2004; Alcamo et al. 2006; Schneider and Woodcock 2008) and recreational uses.

As natural lands continue to be converted for human use, conservation design and planning become increasingly important (Margules and Pressey 2000; Theobald et al. 2000). "Reserve design" is concerned with identifying parcels of land in need of protection to sustain wildlife and other natural resources (Cabeza and Moilanen 2001). Land managers may identify parcels as priorities and secure them through easement, purchase from willing sellers, or other conservation instruments, with the goal of securing sufficient quantity, quality, and connectivity of habitat to meet conservation objectives. The reserve design problem generally assumes that land managers will eventually add all priority parcels to the reserve; however, where many parcels may be in private ownership and must be secured on the open market, acquiring all parcels might not be possible (McDonald-Madden et al. 2008). Funds may not be available to purchase all needed parcels resulting in a timeframe of many years or decades to purchase all required parcels (Meir et al. 2004). Therefore, a reserve design will typically have to be implemented incrementally, which then exposes the land manager to resource, environmental, and socio-economic conditions that can change over the timeframe of reserve construction (Meir et al. 2004).

Researchers project that the southeastern United States will continue to experience high rates of urban and suburban sprawl, further encroaching on natural lands (Terando et al. 2014). Florida has many species and ecosystems of conservation concern (Stein et al. 2000; Knight et al. 2010), and many challenges to the persistence of native species and their habitats including high human population growth and urbanization (Knight et al. 2010; Mackun and Wilson 2011), habitat fragmentation (Brooks et al. 2002), climate change (IPCC 2007; Von Holle et al. 2010), and sea level rise (Noss 2011). The expanding network of roads in Florida cuts through wildlife corridors and is a serious challenge for wide-ranging species such as the Florida black bear *Ursus americanus floridanus* and the endangered Florida panther *Puma concolor coryi* (U.S. Endangered Species Act [ESA 1973, as amended]; Hoctor et al. 2000; Land and Lotz 1996; Larkin et al. 2004). Proper land use planning and protection of critical lands can help mitigate these threats to promote persistence of intact ecological systems.

The objective of our work was to develop a framework to optimize the acquisition of lands that meet the objectives established by the U.S. Fish and Wildlife Service (USFWS) for the formation of the Everglades Headwaters National Wildlife Refuge (EHNWR) in central Florida (Figure 1; USFWS 2012). One of the primary goals of the EHNWR is to protect and restore one of the great grassland and savanna landscapes of eastern North America, conserving one of the nation's prime areas of biological diversity (USFWS 2012). Further, EHNWR managers aim to address pressures from habitat fragmentation and urban development, altered ecological processes, and impacts from global climate change. Additional goals include protection of 43 federally listed and 161 state-listed species found in the area; enhancement of water quantity, quality, and storage for the upper Everglades watershed; and provision of wildlife-dependent recreation and education (USFWS 2012).

We used Marxan with Zones (Watts et al. 2009) as a decision tool to select near-optimal configurations of parcels that met agency-defined targets for habitat acquisition. This software allowed us to vary the proportion of habitat acquired by simple fee purchase vs. conservation easement. A key advantage of Marxan with Zones over the original Marxan software is that the former allows the user to assign any parcel to different zones. In our case, Marxan with Zones allows us to represent fee vs. easement, rather than the binary reserved or unreserved options of the original Marxan. Additionally, Marxan with Zones allows us to define subregions where parcel selection is limited to a single method of acquisition (see Methods). A further innovation of our approach is the use of projections from independent urbanization models, which allows us to explore EHNWR design differences resulting from the different urbanization projections.

Methods

Study area

The EHNWR is located between Lakes Kissimmee and Okeechobee in central Florida (Figure 1). At the time of writing, the EHNWR already protects several thousand acres, but the bulk of land acquisition will occur over the coming years and decades. The region supports existing protected areas, working ranches and farms (e.g., cattle, citrus), military bases, and large water bodies that supply water to the southern portion of Florida as part of the Everglades watershed. Threatened and endangered species as well as other species and habitats of concern for this area include the Florida panther, Florida grasshopper sparrow *Ammodramus savannarum floridanus*, Everglades snail kite *Rostrhamus sociabilis plumbeus*, Florida black bear, Audubon's crested caracara *Caracara plancus audubonii*, and red-cockaded woodpecker *Picoides borealis*, as well as rare habitats of Florida dry prairie, scrub, and sandhill (ESA 1973; Estill and Cruzan 2001).

The Obama administration authorized USFWS to acquire fee-title-interest on up to 50,000 acres (hereafter 20,234 ha) and conservation easements on up to 100,000 acres (hereafter 40,469 ha; current statutory limits) from willing sellers based on the ability of properties to meet

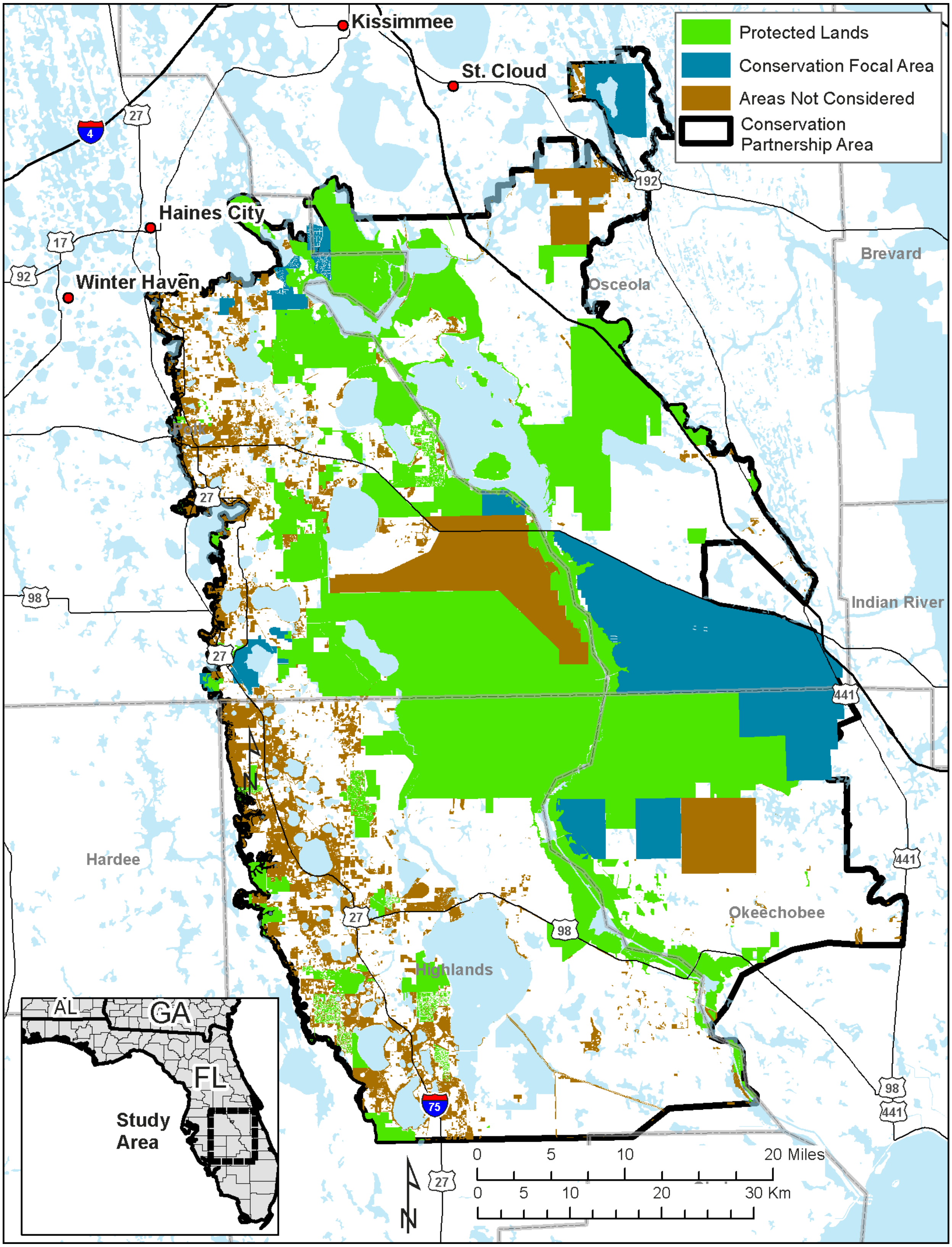


Figure 1. Design of the Everglades Headwaters National Wildlife Refuge in central Florida, 2015. Map of study area showing boundaries of Everglades Headwaters National Wildlife Refuge acquisition area (bold black line), fee zone (dark blue), currently protected areas (green), and areas excluded from consideration for the reserve design (brown). White areas within the acquisition area are available for easement arrangements. Background symbols include county boundaries (grey dashed lines), county names (grey text), major roads (thin black lines with road symbols), and water features (light blue). (Source: USFWS 2012)

the specified objectives for the refuge. Our study area boundaries include large regions where USFWS seeks only conservation easements, and subregions—the Conservation Focal Area—where both easements and fee-title purchases are sought within the noncontiguous 52,609-ha reserve boundary identified by USFWS (Figure 1). The USFWS developed a Land Protection Plan (USFWS 2012) to articulate how and where USFWS, conservation partners, and interested landowners could use land protection to accomplish the objectives for the EHNWR. Using a geographic information system (GIS)-based approach, the USFWS identified specific habitat targets based on listed species habitat needs, including protecting 5,429 ha of dry prairie, 4,097 ha of pine flatwoods, 881 ha of scrub/sandhill, 10,211 ha of wet prairie and marsh, and 3,715 ha of forested wetlands.

Geographic information system analysis

We used the following GIS data files in our analyses:

1) Parcel boundaries and associated 2012 data reported to the Florida Department of Revenue from Highlands, Okeechobee, Osceola, and Polk counties (downloaded from fgdl.org; Data S1, *Supplemental Material*). The parcel file defined the ownership boundaries and provided cost estimates (called "Just Value" by the Florida Department of Revenue) that we used to estimate fee purchase costs in our analysis. Based on discussions with EHNWR personnel and partners, we assigned the cost of an easement to be half of the cost of a fee purchase. We recognize that Just Value data are nearly always lower than market value for parcels, but more accurate data were unavailable.
2) Habitat data for the target habitat types were provided by the Cooperative Land Cover file (ver. 2.3, published 2012 by Florida Natural Areas Inventory), a detailed statewide land cover map developed from existing sources (e.g., Water Management Districts, Department of Transportation) and expert review of aerial photography (Knight et al. 2010). The habitat file delineates the extent of all target habitats, irrespective of ownership boundaries (Data S2, *Supplemental Material*). At the request of our USFWS partners, we restricted our analyses to five habitat types, identified in the GIS file as dry prairie, pine flatwoods, scrub and sandhill (hereafter called xeric), wet prairie and marsh, and forested wetlands.
3) Areas excluded from consideration (provided by USFWS, Vero Beach, Florida; USFWS 2012). This file defines areas that are not of interest for acquisition due to urbanization, excessive disturbance, or other factors (Data S3, *Supplemental Material*).
4) Florida Conservation Lands data (downloaded from fnai.org), which delineate conservation areas that are already protected as of early 2014 (Data S4, *Supplemental Material*).
5) Urbanization forecasts to year 2060 for the study area from two independent models provided by Geodesign Technologies Inc. (Flaxman 2015; Data S5, *Supplemental Material*) and the University of Florida GeoPlan Center (Carr and Zwick 2007; Data S6, *Supplemental Material*).

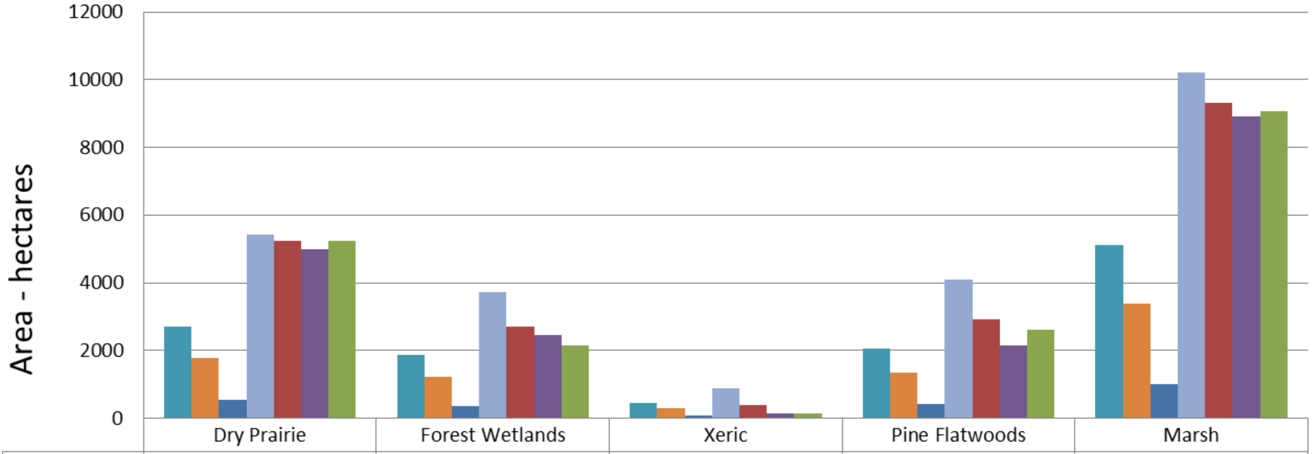
We used GIS software (ESRI ArcMap ver. 10.2.2) to overlay the parcel and habitat layers to identify parcels that contained any amount of the five target habitat types. After inspection of parcels with target habitat (and outside of the areas excluded from consideration and Florida Conservation Land zones), we determined that many of these parcels were poor candidates for portfolio consideration. Many parcels contained habitat patches that were too small, too isolated, or embedded in urbanized areas. Other problematic situations included small wetlands embedded in extensive citrus groves, recently cleared land, ditched or drained pastures, highly disturbed wetlands along major roads, and habitat slivers along developed lake margins. Based on these undesirable traits, discussions with USFWS personnel led us to exclude parcels that were smaller than 40.5 ha. We also evaluated filters to remove poor-quality habitat from the pool available for reserve selection, and found that parcels with less than 20.2 ha of total habitat were generally poor candidates for inclusion. We determined that other filters could be evaluated in future work, including the Critical Lands and Waters Identification Project 4.0 Landscape Integrity Index, which ranks habitat in the region based on land use intensity and habitat patch size (Oetting et al. 2016).

Optimal reserve design

We used myopic decision making to solve a static version of the reserve design problem. That is, we did not attempt to explicitly solve the dynamic reserve design problem, in which the order of purchases is prioritized (Possingham et al. 2009). Rather we looked at static designs for both current and possible future conditions. The appeal of this approach is the relative ease with which researchers can compute solutions for large landscapes with freely available software designed for spatial conservation planning (e.g., Marxan; Watts et al. 2009). We used Marxan with Zones (ver. 2.1), which uses simulated annealing to identify near-optimal zoning configurations that minimize the sum of planning unit and zone boundary costs while attempting to achieve zone-specific targets (Watts et al. 2009). Marxan minimizes reserve costs using the following objective function:

$$\text{minimize}\left(\sum_{k=1}^{n}\text{cost}_j+\sum_{k=1}^{n}\text{CFPF}\cdot\text{penalty}_j+\text{BLM}\cdot\sum_{k=1}^{n}\text{boundary}_j\right),$$

where (for our purposes) cost is the dollar expense of assigning individual parcels k to specific zones j (i.e., fee



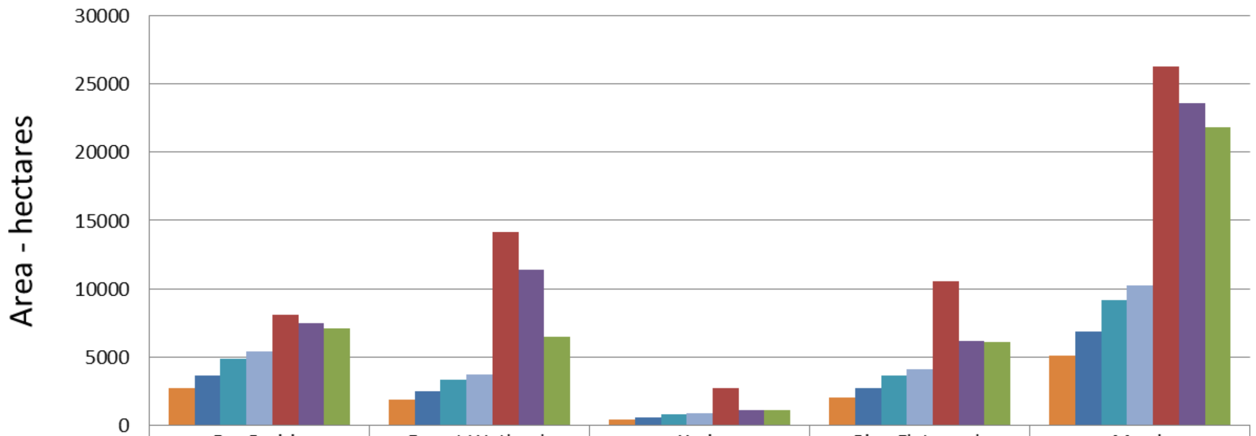
	Dry Prairie	Forest Wetlands	Xeric	Pine Flatwoods	Marsh
🟦 Target 50%	2715	1858	441	2049	5106
🟧 Target 33%	1792	1226	291	1352	3370
🟦 Target 10%	543	372	88	410	1021
🟦 Target 100%	5429	3715	881	4097	10211
🟥 2012	5225	2701	396	2924	9330
🟪 2060-UF	4985	2473	144	2165	8925
🟩 2060-Geo	5224	2153	155	2598	9083

Figure 2. Design of the Everglades Headwaters National Wildlife Refuge in central Florida, 2015. Habitat targets and available habitat within the Conservation Focal Area. For each habitat, the first three graph columns and first three table rows show desired habitat targets allocated at 10, 33, and 50% for the fee simple zone (see Figure 3 for complementary nonfee data). Also shown for each habitat type in the last three graph columns and last three table rows is the available habitat inside the Conservation Focal Area for the three primary scenarios ("2012" for current habitat, "2060-Geo" for the Geodesign urban scenario, and "2060-UF" for the University of Florida urban scenario). Note that targets cannot be met for xeric habitat for any scenario at the 50% level, and cannot be met for xeric habitat at 33% for the University of Florida or Geodesign scenarios.

vs. easement cost), CFPF is the area of target habitat within a parcel, penalty is a scalar for failing to meet a habitat target, BLM (boundary length modifier) is a matrix of scalar cost factors for different zones occurring next to each other, and boundary is the perimeter length of individual parcels (only applied when a parcel is not adjacent to other parcels in the reserve). See Watts et al. (2009) for a formal description of the Marxan algorithm.

We ran a series of Marxan reserve scenarios (defined below) using batch files that invoked Marxan and input files defining the scenarios. We generated primary Marxan input files from ESRI ArcMap (ver. 10.2.2) using statistical summary scripts to generate tables, which we imported into Excel for formatting and exported as comma-delimited text files as required by Marxan. We calculated habitat targets for several different scenarios (defined below; Figures 2–4), and coded these into the appropriate Marxan files. We defined four zones for the Marxan analyses: 1) fee zone (also known as fee-simple), 2) easement zone (also known as nonfee zone), 3) existing protected areas (we locked parcels into this zone in advance), and 4) available or nonselected zones (parcels that were not chosen by Marxan). Marxan automatically assigned each parcel to one of these four zones, based on the zone-specific cost for each parcel to maximize meeting the habitat targets while minimizing the value of the Marxan objective function. Within the Conservation Focal Areas (blue areas in Figure 1) we could assign parcels to either the easement zone or the fee zone, but outside of the Conservation Focal Areas we could only assign parcels to the easement zone. For a given Marxan iteration, we were only able to assign each parcel to a single zone. Calibration of the Marxan runs followed the Marxan *Good Practices Handbook* (Ardron et al. 2010), which included varying important parameter settings such as number of iterations, target penalty factor, and the boundary cost matrix. We examined Marxan output to verify that it met targets and constraints. We followed Watts et al. (2008) to calibrate the boundary cost matrix, which they handled differently than the original Marxan. Although we did not explicitly consider return on investment in our analyses, objectives provided by the USFWS such as optimize habitat protection for several species, wetlands for water quality, and the value of recreational opportunities implicitly incorporate return on investment.

We relied on two independent urbanization models to forecast future development within the study area. Both models rely on historical trends and data on development patterns to develop urbanization suitability layers and consider projected human population growth for Florida (from the Bureau of Economic and Business Research), existing urban lands, and conservation lands. Vargas et al. (2014) previously developed an urbanization



	Dry Prairie	Forest Wetlands	Xeric	Pine Flatwoods	Marsh
🟧 Target 50%	2715	1858	441	2049	5106
🟦 Target 67%	3637	2489	590	2745	6841
🟦 Target 90%	4886	3344	793	3687	9190
🟦 Target 100%	5429	3715	881	4097	10211
🟥 2012	8073	14128	2741	10548	26291
🟪 2060-UF	7522	11399	1127	6165	23591
🟩 2060-Geo	7100	6480	1089	6102	21804

Figure 3. Design of the Everglades Headwaters National Wildlife Refuge in central Florida, 2015. Habitat targets for nonfee protection, and available habitat for the entire study area. For each habitat, the first three graph columns and first three table rows show desired habitat targets allocated at 50, 67, and 90%. Also shown for each habitat type in the last three graph columns and last three table rows is the available habitat for the three primary scenarios ("2012" for current habitat, "2060-Geo" for the Geodesign urban scenario, and "2060-UF" for the University of Florida urban scenario). Note that targets can be met for all habitat types for all scenarios.

model for the USFWS. Flaxman (2015) ran a custom scenario of this model (hereafter "Geodesign") for our study area, which assumed future growth using the 70-y median rate under current local (county) rules and regulations. The Geodesign model uses household income and housing density in the region as a means of projecting where people might be attracted to purchase various types of housing (Vargas et al. 2014). Carr and Zwick (2007) developed the second urban model (hereafter "UF") at the University of Florida. The UF model (Florida 2060) includes many of the suitability factors used in the Geodesign model as well as distance from existing development, development based on projected population growth, and major roads planned in the near future (from the Florida Department of Transportation) as a catalyst for urban growth. Both models provided projections of urban development to the year 2060.

We developed series of scenarios and ran them in Marxan with Zones, using habitat-specific targets as depicted in Figures 2–3. These scenarios reflect different allocations of habitat between the two zones (fee and easement), with the requirement that no fee acquisitions could occur outside of the Conservation Focal Area (where only easements are allowed), whereas both easements and fee acquisition could occur within the Conservation Focal Area. The amount of habitat available varied among three different urbanization scenarios: 1) currently existing habitat (no additional urbanization), 2) habitat forecast to remain in 2060 for the Geodesign model, and 3) habitat forecast to remain in 2060 for the UF model. Within each urbanization scenario three subgroups represented the proportion of total area targeted for each habitat within the fee vs. easement zone (i.e., fee : easement set to 10:90%, 33:67%, and 50:50%). For all scenarios, overall habitat targets (fee and easement combined) were the same; scenarios differed in the proportion of habitat allocated among zones, connectivity parameters, and the amount of habitat available, which differed depending on the urbanization model. We also ran a series of scenarios exploring a range of values for the boundary cost matrix. The base configuration for each scenario had no connectivity influence, which theoretically provided the least expensive and least compact reserve designs. We explored nonzero connectivity values ranging from 0.1 to 1,000,000, following the procedures recommended by Watts et al. (2008).

Results

In the Conservation Focal Area, the Geodesign model projected smaller habitat losses than the UF model (6.7 vs. 9.1%; Figure 2). However, across the entire study area,

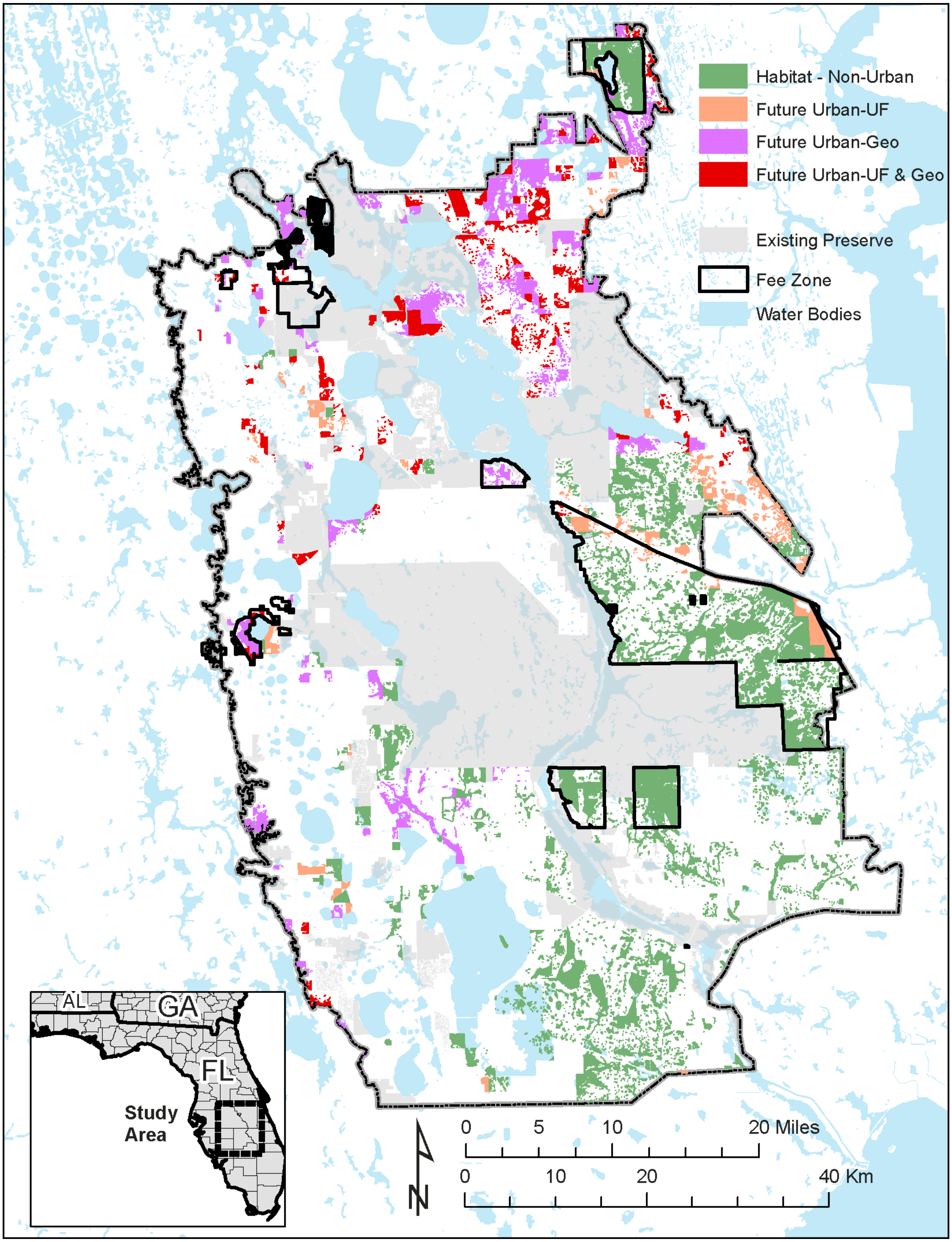
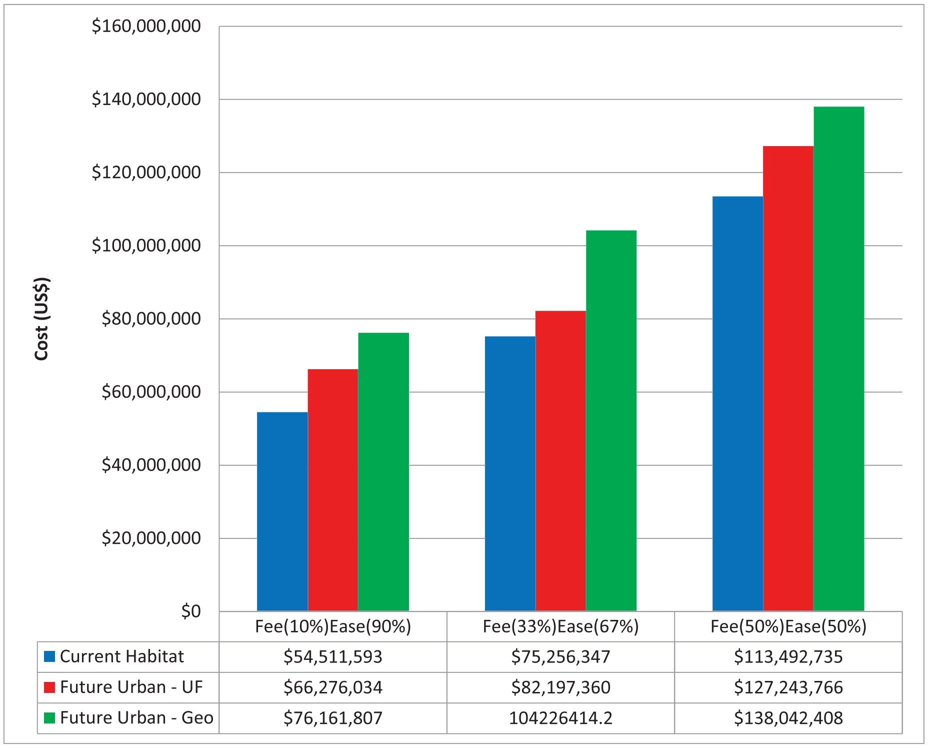


Figure 4. Design of the Everglades Headwaters National Wildlife Refuge in central Florida, 2015. Map showing habitat (all types combined) affected by two urban models (University of Florida [UF] and Geodesign [Geo]). The majority of habitat is not forecast to be urbanized (green polygons), habitat forecast to be developed by both models (red polygons) is prevalent in the north, habitat forecast to be developed only by the UF model (orange polygons), and only by the Geodesign model (magenta polygons). The Conservation Focal Areas ("fee zone") are outlined by solid black lines, and existing protected lands are shaded grey.



	Fee(10%)Ease(90%)	Fee(33%)Ease(67%)	Fee(50%)Ease(50%)
🟦 Current Habitat	$54,511,593	$75,256,347	$113,492,735
🟥 Future Urban - UF	$66,276,034	$82,197,360	$127,243,766
🟩 Future Urban - Geo	$76,161,807	104226414.2	$138,042,408

Figure 5. Design of the Everglades Headwaters National Wildlife Refuge in central Florida, 2015. Average cost for the reserve configurations selected by Marxan with Zones under the three different fee : easement scenarios for current habitat conditions and under the two urban models (University of Florida [UF] and Geodesign [Geo]).

the Geodesign model projected greater habitat losses to urbanization than the UF model (31.0% vs. 20.0%; Figure 3). Xeric habitat showed the largest percentage of losses for all scenarios (range: 39.0 to 64%). The majority of habitats within the study area are not forecast by either urban model to be developed by 2060 (Figure 4; green polygons). The two models showed some degree of overlap or agreement in parcels forecast for development, especially in the northern part of the study area (Figure 4; red and green polygons). The area of nonoverlap is focused in the north for the Geodesign model (Figure 4; magenta polygons), while the UF model shows more development in the east (Figure 4; orange polygons).

We could meet habitat targets for most scenarios, except as noted above when available amounts of xeric habitats were less than targeted for fee purchase in the Conservation Focal Area. Xeric habitat was the only one of the five habitat types to have insufficient area to meet targets for some scenarios. Xeric targets were not achievable for fee purchase within the Conservation Focal Area for the Geodesign and UF urban scenarios at a fee purchase scenario of 33% (Figure 2); nor could these targets be achieved for fee purchase within the Conservation Focal Area at 50% of total target for any scenario (Figure 2). Comparison of different fee : easement ratio scenarios showed the expected increase in cost as the proportion of fee purchases increased (Figure 5). Using Just Value, total costs ranged from a low of just over $54 million to just over $138 million. This compares with USFWS's preliminary estimate of $398 million (USFWS 2012). Urbanization increased the total reserve cost for a given fee : easement scenario, and the Geodesign model resulted in consistently higher costs than the UF model (Figure 5).

Under all scenarios, reserve configurations required less than the 60,703-ha size limit (range: 38,364 to 44,920 ha), and stayed well below the 20,234-ha fee limit and 40,469-ha easement limit (Figure 6). The number of parcels the simulations selected for the fee and easement zones was similar among the current and urban groups, ranging from 174 to 196 parcels (Figure 6). Within a given urbanization scenario, configurations with higher proportions of nonfee acquisition had more total land area and more individual parcel than configurations with higher proportions of fee acquisition (Figure 6). The Marxan with Zones surrogate for connectivity (boundary-zone cost) had almost no influence on the spatial compactness or connectivity of portfolios selected by different scenarios. Due to landowner sensitivities and in order to not adversely impact the land acquisition efforts of USFWS, we are unable to show reserve configurations.

Discussion

The Marxan approach finds near-optimal solutions to the minimum-set problem of selecting individual parcels that meet habitat area targets at the lowest possible costs. Marxan with Zones adds in the additional capability over the original Marxan of determining

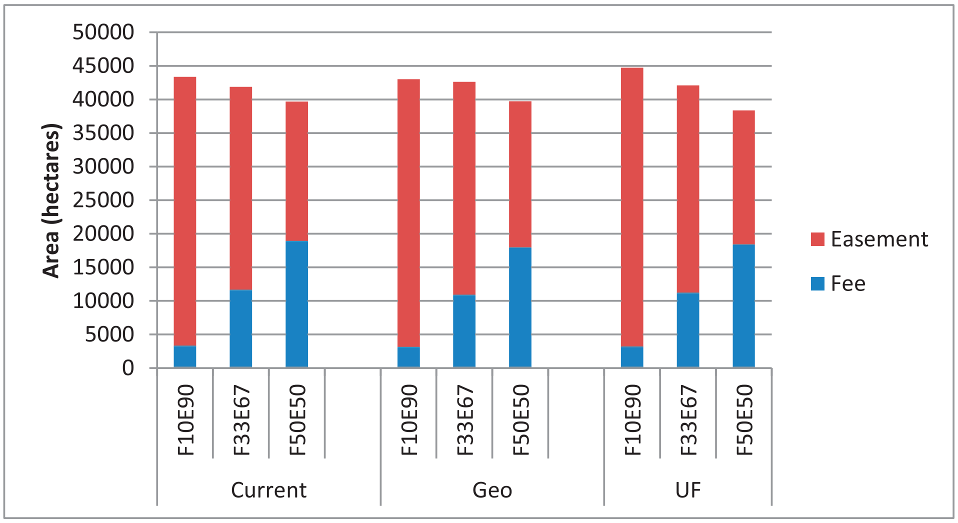


Figure 6. Design of the Everglades Headwaters National Wildlife Refuge in central Florida, 2015. Parcel area in hectares for fee and easement zones for the best reserve configuration determined by Marxan with Zones for each scenario. There are nine scenarios portrayed, with three major groups along the x-axis for currently existing habitat, and habitat remaining for the Geodesign and University of Florida urban models. The three subgroups within each major group are for the proportion of area allocated for fee (10, 33, and 50%) vs. easement (90, 67, and 50%).

near-optimal assignments of parcels to different zones, in this case to protection by fee purchase vs. easement. Marxan with Zones successfully generated reserve designs that met all of our habitat target goals (when achievable) and properly allocated parcels between the fee and easement zones, finding reserve configurations that fell well below the 60,703-ha limit. As expected, reserve costs increased as the proportion of fee purchases increased, reflecting the higher cost of fee acquisition over easement arrangements. Reserve costs increased under the influence of the urbanization models, likely reflecting the reduced number of high-quality parcels available for selection. The total number of parcels required for each reserve design was similar among all scenarios, suggesting that transaction costs, which are generally equivalent regardless of parcel size and small compared to purchase price, are not a significant consideration in this reserve design setting.

Marxan output provided detailed information that is valuable for on-the-ground conservation planning, including lists of individual parcels selected for each reserve design and selection frequency of each parcel, along with costs, ownership, and other detailed information. We also used Marxan output to generate reserve maps and parcel selection frequency maps that showed differences among scenarios. Due to privacy and sensitivity issues of parcels considered for acquisition, we do not show such details here. Spatial compactness of reserve configurations changed little by increasing the Marxan compactness parameters (i.e., BLM). Marxan runs with compactness parameters set to zero already showed high compactness, likely reflecting allocation requirements within the spatially restricted Conservation Focal Area, and the clustering of large, inexpensive parcels in the southern and eastern portions of the study area. In general, because Marxan only considers parcels connected if they share boundaries, differences in compactness resulting from using different BLM values in Marxan are not directly relatable to differences in connectivity as measured by software that models flow of species across landscapes. Users can input Marxan results into such software for additional analyses (e.g., McRae et al. 2008; Saura and Rubio 2010) or use connectivity values in place of the BLM values (Beger et al. 2010). In our case, the high similarity and compactness of reserve configurations generated with very different BLM values suggests that additional connectivity analyses are not warranted.

Xeric habitat was the only target that we could not meet for five of the nine scenarios. This target failure occurred only for fee purchase within the Conservation Focal Area, and is likely due to the habitat's restricted distribution in the west of the study area, which is a region that is already urbanized. Both urban models forecast large xeric losses to urbanization. We found that we could generally meet xeric targets if we included parcels smaller than the 40.5-ha limit in the analysis (results not shown). Special treatment of xeric habitat may be warranted (e.g., targeting smaller parcels), especially considering the expected losses to development, the high levels of species endemism, and the endangered status of both species and habitat (ESA 1973).

The urbanization models provided information that was useful for evaluating reserve designs. The two models showed considerable agreement over which habitat patches they did not forecast to be developed, and some agreement over which parcels they forecast would be developed. From a simple multimodeling perspective, we could consider the areas of model agreement to have less uncertainty than areas where the two urban models differed. However, large, unspecified levels of uncertainty exist in these urbanization forecasts, and we must consider this uncertainty when interpreting model outputs. Marxan also provides selection frequency statistics for each parcel, which help identify parcels that are especially important for achieving near-optimal reserve designs. We can consider the selection frequency for each parcel a measure of irreplaceability; it is equivalent to the number of Marxan solutions that would be incomplete if that parcel were lost (Ardron et al. 2010). Our use of Marxan provides a landscape-scale, coarse filter for habitat and biodiversity conservation in our study area. These outputs would benefit from refinement using a fine-filter approach to ensure that reserve design meets sufficient habitat amounts and configuration needs for the focal species (Noss 1987).

The incorporation of urban forecasts into the reserve design process produced results that are subject to differing interpretations. From a "threat analysis" perspective, the urban forecasts suggest which habitat patches are at higher risk of development, and possibly warrant higher-priority protection before development can occur. The Peninsular Florida Landscape Conservation Cooperative (a conservation-focused public–private partnership working across jurisdictional boundaries) is also grappling with the decision of where and how to protect land as they look to establish long-term targets for conservation in this region with impending urbanization (Romañach et al. 2016). Prioritizing protection of parcels at highest risk of development may be especially important if the parcels include vulnerable or irreplaceable resources, such as xeric habitat, especially scrub. Yet costs for acquisition may also increase, because owner willingness to sell or establish easements for conservation may decrease as prospective property values increase. Alternatively, the urban models might highlight parcels that development is likely to embed in an undesirable urban matrix. Difficulties associated with proximity to urban development include fire management issues, introduction of exotic species, and edge effects (Noss et al. 2014). There may be political or cultural reasons to avoid incorporating land into reserves where conflicting demands or needs are prevalent. From this perspective, avoiding parcels in areas that models project to be urbanized may be desirable, especially if reserve designers can meet targets elsewhere. This strategy also may help reduce urban sprawl; preserving outlying areas may encourage more development near urban centers, resulting in more compact development (Hafen 2016). In this study, available habitats exceeded targets even under urban projections, except for xeric habitat, which was limited in the Conservation Focal Area. Under these circumstances, treating xeric habitat differently than the more abundant habitat types, which are available away from areas expected to develop, may be warranted. Our results indicate that loss of habitat associated with the urbanization scenarios results in increased costs for reserve designs, likely reflecting the reduced availability of less-expensive parcels that allow reserve designers to meet targets.

We relied on property value estimates provided by county tax appraisers, which are nearly always lower than actual market values. Furthermore, this difference, referred to as the "equalization rate," may differ from county to county, and may be larger in areas more prone to urbanization with high demand compared to rural areas where demand is lower. Therefore, actual dollar values provided by this analysis are underestimates of the actual market value. A factor that is beyond the scope of this analysis is demand for agricultural lands, such as citrus groves. Finally, the Marxan analysis we used is static; it assumes that the reserve designers can make protection arrangements for each scenario all at once, whereas in reality the reserve managers will make purchases incrementally over a period of decades, and many target properties may be lost during that period. Alternative static approaches are available, such as Zonation (Moilanen 2007; Delavenne et al. 2011), which can provide deterministic, target-based solutions as well as a prioritized list of purchases. However, Zonation cannot handle the complex, nonbinary problem definition for which Marxan with Zones is designed (Watts et al. 2009). More recently, modelers have developed integer linear programming approaches that find near-optimal or a single, optimal solution, but this approach may be difficult or infeasible to implement for complex, nonlinear problems that are solvable by Marxan with Zones (Beyer et al. 2016). Modelers are also developing dynamic approaches that account for incremental protection or loss of parcels over time (Bonneau et al. 2018).

The Florida coast is vulnerable to sea level rise, and coastal retreat and migration inland is expected to increase demand for undeveloped land away from the coast (Hafen 2016). Although neither of the urban models considers coastal retreat due to sea level rise, we expect that incorporating rising sea levels into the two urban models would accelerate the rate of urban growth away from the coast without significantly changing the overall inland growth patterns. Viewed this way, urbanization could occur more rapidly than forecast if future sea-level–rise impacts accelerate coastal retreat. Incorporating urbanization model output into the Marxan analysis indicated that as urbanization increased, reserve cost also increased. Urban planners could perhaps mitigate some of the habitat losses associated with urbanization if development followed a smart growth pattern, increasing urban density and reducing sprawl. Because urbanization is more extensive in the northern portion of the region, reserve designs that take urbanization into account shift reserve boundaries to the south. Thus, when comparing the reserve designs that result with and without urbanization, parcels that both urban scenarios select frequently may be more robust choices. Additional benefits of avoiding areas likely to be urbanized include reduced edge effects, reduced issues with controlled burns, reduced road kill, and improved water quality.

Supplemental Material

Please note: The Journal of Fish and Wildlife Management is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Data S1. Parcel boundaries and associated 2012 data reported to the Florida Department of Revenue from Highlands, Okeechobee, Osceola, and Polk counties.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S1 (1,568,252 KB ZIP).

Data S2. Statewide land cover map published 2012 by Florida Natural Areas Inventory.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S2 (384,615 KB ZIP).

Data S3. U.S. Fish and Wildlife Service–defined areas excluded from consideration of the Everglades Headwaters National Wildlife Refuge design.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S3 (2051 KB ZIP).

Data S4. Protected areas within the state of Florida.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S4 (1288 KB ZIP).

Data S5. Urbanization forecasts to year 2060 for the study area, developed by Geodesign Technologies Inc.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S5 (1288 KB ZIP).

Data S6. Urbanization forecasts to year 2060 for the study area, developed by University of Florida Urban and Regional Planning department.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S6 (3660 KB ZIP).

Reference S1. [IPCC] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Core writing team: Pachauri RK, Reisinger A, editors. Geneva, Switzerland: Intergovernmental Panel on Climate Change.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S7; also available at https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf, http://www.webcitation.org/70px2I5K5 (6369 KB PDF).

Reference S2. Oetting J, Hoctor T, Volk M. 2016. Critical Lands and Waters Identification Project (CLIP): Version 4.0 technical report—September 2016. Report of Florida Natural Areas Inventory, Florida State University and Center for Landscape Conservation Planning, University of Florida to the US Fish and Wildlife Service and the Peninsular Florida Landscape Conservation Cooperative.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S8; also available at http://wwwfnaiorg/pdf/CLIP_v4_technical_reportpdf, http://www.webcitation.org/6xy3ZIsmi (7254 KB PDF).

Reference S3. [USFWS] US Fish and Wildlife Service. 2012. Land protection plan for the establishment of the Everglades Headwaters National Wildlife Refuge and Conservation Area. Atlanta, Georgia: U.S. Department of the Interior, Fish and Wildlife Service, Southeast Region.
Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-060.S9; also available at https://www.fws.gov/uploadedFiles/Region_4/NWRS/Zone_2/Everglades_Headwaters_Complex/Everglades_Headwaters/PDFs/FinalLPPEvergladesHeadwatersNWR.pdf, http://www.webcitation.org/6xy3ccAKu (4309 KB PDF).

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