Articles

Potential Impacts of Future Urbanization and Sea Level Rise on Florida’s Natural Resources

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Abstract

As urban development continues to encroach into natural systems, these ecosystems experience increasing degradation to their form and function. Changing climatic conditions further compound the losses in biodiversity and ecosystem function. The state of Florida is known for its biodiversity but has experienced declines in species populations and habitats because of urbanization and sea level rise. Because Florida benefits from a multibillion-dollar income from natural resources tourism, these declines challenge the state’s economy. In this study, we assessed the potential future impacts of urbanization and sea level rise on a suite of conservation targets that have been set for the state. We developed six scenarios of all combinations of intermediate and high sea level rise paired with two types of urbanization, sprawling and compact, in both 2040 and 2070 to examine the potential future threats to conservation targets in High Pine and Scrub, Coastal Uplands, and Freshwater Aquatics ecosystems. Our results show projected decreases in extent and area of these priority ecosystems into the future. Under Florida’s current trends in urbanization practices, projections indicate a greater impact on conservation targets than if sprawl reduction practices are implemented. Projections indicate that Coastal Uplands will experience the greatest loss in area, at up to 47%. Conservation-focused urban planning and climate adaptation strategies can help protect Florida’s natural resources with benefits to Florida’s tourism economy as well as critical ecosystem functions and services such as coastal flood protection and storm surge risk reduction.

Keywords: coastal; freshwater; landscape conservation cooperative; pine; scrub; wetland

Introduction

Natural resource managers face increasing challenges for conservation planning in changing ecosystems. Human impacts on ecosystems have increased with advances in technology and the resulting increases in human populations and encroachment into natural areas (Vitousek et al. 1997). Changes in climatic conditions present novel conditions for organisms and have led to biodiversity loss and changes in ecosystem function (Bellard et al. 2012; Cardinale et al. 2012; Hooper et al. 2012). Most notably, these changes have led to range shifts and phenological changes (Parmesan and Yohe 2003) as well as to changes in population dynamics, ecological community assemblages, and nonnative species invasions (Walther 2010). Uncertainty surrounding future change and varying projections of ecological responses to change pose even greater challenges for natural resource managers (e.g., Thuiller 2004).

The state of Florida is well known for its terrestrial and marine biodiversity (Millsap et al. 1990), yet many of its ecosystems are under threat (Florida Natural Areas Inventory 2018). Florida’s diverse species and habitats attract millions of tourists and bring in $9 billion per year from fishing, hunting, and wildlife watching (U.S. Census Bureau 2011). Florida’s 13,576 km of coastline leaves many of its ecosystems vulnerable to sea level rise (SLR),
in addition to threats from urban development, increasing temperature, and altered precipitation regimes (Noss 2011).

Setting conservation targets, the measurable expressions of desired resource conditions, is a commonly used means for natural resource managers to focus their conservation needs and goals (Groves et al. 2002; Parrish et al. 2003). Conservation practitioners have assessed and prioritized the conservation needs of Florida’s species, habitats, and ecosystems (e.g., Florida Natural Areas Inventory 2000, 2018; Oetting et al. 2016). Decades ago, 44% of Florida’s vertebrate species were reported to be in population decline (Millsap et al. 1990). Since that time, environmental conditions have worsened because of increasing urbanization (Terando et al. 2014) and SLR (Noss 2011). These declines in ecosystem health and function emphasize the need for Florida’s natural resource managers to set conservation targets as a way to prioritize ecosystem needs and focus resources toward achieving conservation goals.

The Peninsular Florida Landscape Conservation Cooperative (PFLCC), a public–private partnership focused on applied conservation science to inform management decisions, renewed efforts to establish conservation targets across the state of Florida. The PFLCC had an advantage of developing targets in a data-rich state and was able to make use of existing conservation and management plans as well as research and monitoring data, such as the Florida Natural Areas Inventory’s statewide Conservation Needs Assessment, the Critical Lands and Waters Identification Project (CLIP), Florida 2060 projected urban development, and Florida’s State Wildlife Action Plan for conserving wildlife and natural areas. The PFLCC subsequently developed a formal process for establishing conservation targets and then worked with subject matter experts to define which ecosystems were in greatest need of protection and selected explicit targets for conservation into the future (Románach et al. 2016).

The objective of our work was to model susceptibility scenarios resulting from urbanization and SLR to understand potential future impacts on the PFLCC’s conservation targets. We modeled six scenarios of urbanization and SLR to understand the future susceptibility of a subset of PFLCC conservation targets. We used conservation targets for three of the PFLCC’s major categories for protection, termed Priority Resources (Románach et al. 2016)—High Pine and Scrub, Coastal Uplands, and Freshwater Aquatics—the three Priority Resources for which the PFLCC had defined conservation targets at the time of writing. The six scenarios were all possible combinations of intermediate and high SLR paired with two types of urbanization projections, sprawling and compact, for both 2040 and 2070. Our outputs identify the spatial extent of potential threats to conservation targets on a statewide scale and provide the PFLCC with a foundation for the assessment and monitoring of natural resources, a framework for prioritizing conservation efforts, and information for communicating priorities.

Methods

We developed six scenarios of urbanization and SLR to understand the future susceptibility of 14 of the PFLCC conservation targets in three Priority Resources (Table 1). The PFLCC uses the Florida state boundary, broader than the PFLCC boundary, as the boundary for defining targets for coordination of conservation efforts with other landscape conservation cooperatives (Figure 1). For scenario modeling, we extracted projected urbanized and inundated areas to create spatial composites of potential future impacts on conservation targets. We calculated the amount of area impacted by projected urbanization and SLR and the percentage of total area affected of each target, for each scenario.

Priority Resources

Priority Resource definitions were adapted by the PFLCC from Kawula (2018). High Pine and Scrub is defined as hills with mesic or xeric woodlands or shrublands; canopy, if present, is open and consists of pine or a mixture of pine and deciduous hardwoods (Data A1, Archived Material). Coastal Uplands is defined as mesic or xeric communities restricted to barrier islands and near shore with woody or herbaceous vegetation; other communities may also occur in coastal environments (Data A2, Archived Material). Freshwater Aquatics is defined as natural rivers and streams where stream flow, morphology, and water chemistry are not substantially modified by human activities, or native biota are dominant (Data A3, Archived Material). It also includes natural inland lakes and ponds where the trophic state, morphometry, and water chemistry are not substantially modified by human activities, or native biota are dominant. All three Priority Resource layers were obtained from the Critical Land and Waters Identification Project 4.0 Aggregated Priorities model (Oetting et al. 2016).

Urbanization

Through consultation with the PFLCC, we selected three, 1000 Friends of Florida urbanization layers: 1) Florida 2060 projection for the year 2040 (Zwick and Carr 2006; Data A4, Archived Material), 2) Florida “Alternative” for 2070 (Data A5, Archived Material), and 3) “Trend” projections for 2070 (Carr and Zwick 2016; Data A6, Archived Material). The Florida 2060 (FL2060) project, conducted in 2006, developed urbanization projections for 2040 by using trending development patterns at that time. The Florida 2070 (FL2070) project, conducted in 2016, developed two future scenarios for 2070 based on population growth estimates from the Florida Bureau of Economic and Business Research. Urbanization in the Alternative 2070 layer includes more compact development (higher density and a smaller spatial extent) and an increased acreage of protected lands compared with Trend (larger spatial impact per capita). Urbanization from the Trend 2070 layer includes development continuing along current patterns with the same
population as Alternative but spread out, which means
growth at lower densities compared with the Alternative.
We used different methods to develop the projected
urbanization layers in FL2060 and FL2070 as well as to
create the respective baseline urbanization layers.

For the 2040 scenario modeling, we used the 2040
spatial layers from FL2060. For the 2070 scenario
modeling, we used layers from FL2070. Because these
projects used different methodologies in developing the
urbanization layers, the projections suggest that some
areas will be urbanized in 2040, but not in 2070. In
addition, when we compared the respective baselines
(FL2060’s baseline is for 2005 and FL2070’s baseline is for
2010), we found that the 2005 urban baseline contains
more urban areas than the 2010 baseline by approxi-
mately 500,000 ha. This difference may be attributed to
the FL2060 methodology that classified all vacant platted
residential properties as urban, even if the land cover
type for that parcel was not urban (Zwick and Carr 2006).
Because the FL2070 2010 baseline urbanization scenario
appeared to provide a more accurate classification of
existing urbanization (based on comparison to satellite
imagery), we used this baseline for all susceptibility
modeling (Data A7, Archived Material).

The differences between baseline urbanization layers
and inconsistencies between urban growth projections
prompted us to modify the FL2060 urbanization
projection for 2040 to make it comparable with the
FL2070 projection for 2070. First, we removed overlap-
ping 2005 baseline urban sites from the 2040 urban
growth layer. Next, we added urban areas from the 2010
baseline to the 2040 urban layer. Last, some areas
projected as urban in 2040 were not classified as urban
in 2070, which is problematic for a comparison of growth
from the baseline. We removed any urban areas from the
2040 projection that were not classified as urban in either of the 2070 projections (Alternative or Trend).
Having removed these discrepancies between projec-
tions, we were able to use the same 2010 urbanization
baseline across all scenarios, making our comparisons
consistent.

Sea Level Rise

We selected SLR inundation layers developed by the
University of Florida (UF) GeoPlan Center (University of
Florida GeoPlan Center 2014; Data A8, Archived Material).
These layers used U.S. Army Corps of Engineers SLR
projections and Sea-Level Change Curve Calculator
version 2015.46 (Huber and White 2015) and National
Oceanic and Atmospheric Administration (NOAA) tidal
gauge data and tidal surfaces to develop SLR inundation
layers at a 5-m horizontal resolution for each of Florida’s
36 coastal counties. The SLR layers were developed for
each county by using local gauge data and sea level
trends. The UF GeoPlan Center used a modified bathtub
approach where isolated areas not hydrologically con-
ected to the coast were removed from inundation.

The UF GeoPlan Center developed SLR inundation
layers for five scenarios. Through coordination with the
PFLCC to meet their needs, we selected the U.S. Army
Corps of Engineers’ intermediate and high SLR pro-
jections. We selected SLR inundation layers for the years
2040 and 2070. Sea level rise is projected to differ
regionally because of differences in factors such as changes in ocean current, surface winds, and expansion of warming water (Church et al. 2013); therefore, SLR values provided below are given as the ranges provided within Florida by the UF GeoPlan Center.

The resulting six scenarios are as follows:

1) 2040 Urban Int SLR: intermediate SLR (0.15–0.21 m) with Florida 2060’s modified urbanization projection for 2040,
2) 2040 Urban High SLR: high SLR (0.36–0.40 m) with Florida 2060’s modified urbanization projection for 2040,
3) 2070 Alt Urban Int SLR: intermediate SLR (0.30–0.40 m) with Florida 2070’s alternative urbanization projection for 2070,
4) 2070 Alt Urban High SLR: high SLR (0.82–0.91 m) with Florida 2070’s alternative urbanization projection for 2070,
5) 2070 Trend Urban Int SLR: intermediate SLR (0.30–0.40 m) with Florida 2070’s trend urbanization projection for 2070, and
6) 2070 Trend Urban High SLR: high SLR (0.82–0.91 m) with Florida 2070’s trend urbanization projection for 2070.

**Workflow**

We developed a workflow with points of evaluation to determine adequate representation and quality of input data. We clipped each input conservation target (Table 1) to its respective Priority Resource. Because the objective is to examine the susceptibility of the Priority Resources to future urbanization, we removed areas overlapping with the FL2070 2010 baseline urban layer from the input data to calculate accurate estimates of areas lost to future urbanization. For each prepared set of input data, we spatially extracted the urbanization and SLR projections according to the six model scenarios. The results
Table 2. Study objective was to model susceptibility scenarios resulting from urbanization and sea level rise (SLR) to understand their potential future impacts on the Peninsular Florida Landscape Conservation Cooperative conservation targets, completed in 2018. The area (km²) and percent (%) decrease in area of each model input (i.e., conservation target) for the High Pine and Scrub Priority Resource for each future model scenario of urbanization (Urban) and SLR. The baseline area of target represents the current extent of the input model data with the 2010 urban baseline extracted. Each area and percent decrease in area is represented for Critical Lands and Waters Identification Project Priority 1 and 2 (CLIP P1 and CLIP P2, respectively). The CLIP Landscape Integrity Index values ≥ 8 (high ecological integrity) and Florida Ecological Greenways Network Priority 1 (P1 = Critical Linkages) were used for calculations. We also present the area and percent change in area for the entire High Pine and Scrub Priority Resource for CLIP P1 and CLIP P2.

| Model data and scenario | High Pine and Scrub Priority Resource | Protected status | Landscape Integrity (≥ 8) | Ecological Greenways (P1) | Gopher tortoise | Red-cockaded woodpecker | Sandhill bird index |
|-------------------------|--------------------------------------|------------------|--------------------------|---------------------------|----------------|------------------------|---------------------|
|                         | Baseline area of target (km²)         | CLIP P1          | CLIP P2                  | CLIP P1                   | CLIP P2             | CLIP P1                   | CLIP P2             |
|                         | Area (km²)                           | 5,101.0          | 260.6                    | 3,978.1                   | 99.1               | 4,438.8                   | 215.1               |
| 2040 Urban Int SLR      | 4,999.1                              | 246.8            | 3,977.9                  | 99.1                      | 4,395.4             | 209.0                    | 3,527.6             |
| 2040 Urban High SLR     | 4,998.1                              | 246.8            | 3,977.2                  | 99.1                      | 4,395.0             | 209.0                    | 3,523.5             |
| 2070 Alt Urban Int SLR  | 4,859.9                              | 229.0            | 3,977.4                  | 99.1                      | 4,304.0             | 196.9                    | 3,516.8             |
| 2070 Alt Urban High SLR | 4,850.4                              | 228.8            | 3,969.7                  | 99.0                      | 4,300.0             | 196.8                    | 3,515.6             |
| 2070 Trend Urban Int SLR| 4,711.1                              | 220.6            | 3,977.1                  | 99.1                      | 4,219.0             | 190.0                    | 3,499.1             |
| 2070 Trend Urban High SLR| 4,701.7                              | 220.4            | 3,969.4                  | 99.0                      | 4,215.1             | 190.0                    | 3,458.0             |
| % decrease from baseline| 2040 Urban Int SLR                    | 2.0              | 0.004                    | 0.003                     | 1.0                  | 0.97                     | 0.14                |
|                         | 2040 Urban High SLR                   | 2.0              | 0.02                     | 0.01                      | 3.0                  | 0.87                     | 0.30                |
|                         | 2070 Alt Urban Int SLR                | 4.7              | 0.02                     | 0.01                      | 3.0                  | 0.87                     | 0.30                |
|                         | 2070 Alt Urban High SLR               | 4.9              | 0.12                     | 0.02                      | 3.15                 | 0.30                     | 0.30                |
|                         | 2070 Trend Urban Int SLR              | 7.6              | 0.12                     | 0.02                      | 5.0                  | 0.11                     | 0.30                |
|                         | 2070 Trend Urban High SLR             | 7.8              | 0.15                     | 0.02                      | 5.0                  | 0.11                     | 0.30                |

n/a = not applicable.

are spatial composites for each of the six scenarios (Data A9, Archived Material). For each spatial composite and for the baselines with 2010 urban areas removed, we calculated the areas classified as either CLIP Aggregate Priority 1 or 2, the highest conservation priorities for the state (Oetting et al. 2016). We also calculated the percentage of area removed due to urbanization and SLR, relative to the baseline.

Results

Across all scenarios, we noted that the loss in area due to urbanization and SLR was more pronounced in the 2070 than in the 2040 scenarios for all Priority Resources: High Pine and Scrub, Coastal Uplands, and Freshwater Aquatics (Tables 2–4). Overall, projections indicate SLR will have a greater impact than urbanization, largely through losses to Coastal Uplands (Figure 2). Outputs are available online as a U.S. Geological Survey data release (http://doi.org/10.5066/P99EQGZW).

For the High Pine and Scrub Priority Resource (Table 2), we found a small effect of urbanization and SLR scenarios on protected area status and Ecological Greenways (ecologically connected public and private conservation lands). There was also a general trend of greater percentage of area lost due to urbanization and SLR for the species-based targets (gopher tortoise

Figure 2. Study objective was to model susceptibility scenarios resulting from urbanization and sea level rise (SLR) to understand their potential future impacts on the Peninsular Florida Landscape Conservation Cooperative conservation targets, completed in 2018. Difference in the percent of area lost (of Critical Lands and Waters Identification Project Priority 1 and 2 combined) between SLR scenarios (High and Intermediate [Int]), holding urbanization scenarios constant for High Pine & Scrub (HPS), Coastal Uplands (CU), and Freshwater Aquatics (FA) Priority Resources. Higher values indicate a greater difference in the percent area lost between High and Intermediate SLR.
Table 3. Study objective was to model susceptibility scenarios resulting from urbanization and sea level rise (SLR) to understand their potential future impacts on the Peninsular Florida Landscape Conservation Cooperative conservation targets, completed in 2018. The area (km$^2$) and percent (%) decrease in area of each model input (i.e., conservation target) for the Coastal Uplands Priority Resource for each future model scenario of urbanization (Urban) and SLR. The baseline area of target represents the current extent of the input model data with the 2010 urban baseline extracted. Each area and percent decrease in area is represented for Critical Lands and Waters Identification Project Priority 1 and 2 (CLIP P1 and CLIP P2, respectively). The CLIP Landscape Integrity Index values $\geq 8$ (high ecological integrity) and Florida Ecological Greenways Network Priority 1 (P1 = Critical Linkages) were used for calculations. We also present the area and percent change in area for the entire Coastal Uplands Priority Resource for CLIP P1 and CLIP P2.

| Model data and scenario | Coastal Uplands Priority Resource | Protected status | Landscape Integrity (≥ 8) | Ecological Greenways (P1) | American oystercatcher | Snowy plover |
|-------------------------|---------------------------------|-----------------|---------------------------|--------------------------|------------------------|--------------|
| CLIP P1 | CLIP P2 | CLIP P1 | CLIP P2 | CLIP P1 | CLIP P2 | CLIP P1 | CLIP P2 |
| Baseline area of target (km$^2$) | 256.7 | 13.9 | 203.2 | 3.4 | 263 | n/a | 86.9 | 9.0 | 38.9 | 3.2 |
| Area (km$^2$) | 2040 Urban Int SLR | 246.2 | 12.7 | 197.8 | 3.3 | 24.4 | n/a | 81.4 | 8.1 | 37.9 | 3.1 |
| | 2040 Urban High SLR | 236.8 | 12.2 | 191.0 | 3.2 | 73.7 | 0.7 | 22.0 | n/a | 77.7 | 7.7 | 36.5 | 2.9 |
| | 2070 Alt Urban Int SLR | 237.9 | 12.2 | 192.3 | 3.2 | 57.9 | 0.7 | 22.6 | n/a | 78.1 | 7.8 | 36.7 | 3.0 |
| | 2070 Alt Urban High SLR | 183.6 | 10.1 | 147.5 | 2.7 | 40.8 | 0.6 | 14.0 | n/a | 63.4 | 6.2 | 30.4 | 2.2 |
| | 2070 Trend Urban Int SLR | 235.6 | 12.2 | 192.3 | 3.2 | 57.4 | 0.7 | 22.6 | n/a | 78.1 | 7.7 | 36.7 | 3.0 |
| | 2070 Trend Urban High SLR | 182.1 | 10.0 | 147.5 | 2.7 | 40.4 | 0.6 | 14.0 | n/a | 63.3 | 6.2 | 30.4 | 2.2 |
| % decrease from baseline | 2040 Urban Int SLR | 4.1 | 8.4 | 3.8 | 1.9 | 7.2 | n/a | 6.3 | 9.9 | 2.7 | 4.3 |
| | 2040 Urban High SLR | 7.8 | 12.2 | 8.0 | 5.6 | 16.3 | n/a | 10.6 | 14.1 | 6.1 | 9.3 |
| | 2070 Alt Urban Int SLR | 7.3 | 11.8 | 7.1 | 4.8 | 13.8 | n/a | 10.1 | 13.7 | 5.7 | 9.0 |
| | 2070 Alt Urban High SLR | 28.5 | 27.4 | 34.5 | 24.2 | 46.6 | n/a | 27.1 | 30.9 | 21.9 | 33.1 |
| | 2070 Trend Urban Int SLR | 8.2 | 12.1 | 7.8 | 4.8 | 14.2 | n/a | 10.1 | 14.2 | 5.7 | 8.7 |
| | 2070 Trend Urban High SLR | 29.1 | 27.7 | 35.2 | 24.2 | 46.8 | n/a | 27.1 | 31.3 | 22.0 | 33.0 |
| n/a = not applicable. |

Table 4. Study objective was to model susceptibility scenarios resulting from urbanization and sea level rise (SLR) to understand their potential future impacts on the Peninsular Florida Landscape Conservation Cooperative conservation targets, completed in 2018. The area (km$^2$) and percent (%) decrease in area of each model input (i.e., conservation target) for the Freshwater Aquatics Priority Resource for each future model scenario of urbanization (Urban) and SLR. The Baseline area of target represents the current extent of the input model data with the 2010 urban baseline extracted. Each area and percent decrease in area is represented for Critical Lands and Waters Identification Project Priority 1 and 2 (CLIP P1 and CLIP P2, respectively). The CLIP Landscape Integrity Index values $\geq 8$ (high ecological integrity) were used for calculations. We also present the area and percent change in area for the entire Freshwater Aquatics Priority Resource for CLIP P1 and CLIP P2.

| Model data and scenario | Freshwater Aquatics Priority Resource | Floodplain connectivity | Landscape Integrity (≥ 8) | Plant diversity (no. of sample locations) |
|-------------------------|-------------------------------------|------------------------|---------------------------|------------------------------------------|
| CLIP P1 | CLIP P2 | CLIP P1 | CLIP P2 | CLIP P1 | CLIP P2 | CLIP P1 | CLIP P2 |
| Baseline area of target (km$^2$) | 2,271.0 | 1,579.0 | 127.2 | 50.0 | 169.6 | 58.5 | 141 | 111 |
| Area (km$^2$) | 2040 Urban Int SLR | 2,266.8 | 1,578.1 | 124.5 | 49.5 | 166.6 | 58.1 | 141 | 109 |
| | 2040 Urban High SLR | 2,264.8 | 1,577.9 | 123.3 | 49.3 | 165.0 | 58.0 | 141 | 109 |
| | 2070 Alt Urban Int SLR | 2,263.8 | 1,576.4 | 122.7 | 48.5 | 165.0 | 57.5 | 141 | 109 |
| | 2070 Alt Urban High SLR | 2,261.3 | 1,576.0 | 121.0 | 48.2 | 163.2 | 57.3 | 141 | 109 |
| | 2070 Trend Urban Int SLR | 2,262.6 | 1,576.4 | 121.1 | 48.4 | 164.4 | 57.4 | 141 | 109 |
| | 2070 Trend Urban High SLR | 2,260.1 | 1,576.0 | 120.4 | 48.1 | 162.7 | 57.2 | 141 | 109 |
| % decrease from baseline | 2040 Urban Int SLR | 0.2 | 0.1 | 2.1 | 1.0 | 1.8 | 0.7 | 0.0 | 1.8 |
| | 2040 Urban High SLR | 0.3 | 0.1 | 3.1 | 1.2 | 2.7 | 0.9 | 0.0 | 1.8 |
| | 2070 Alt Urban Int SLR | 0.3 | 0.2 | 3.5 | 3.0 | 2.7 | 1.7 | 0.0 | 1.8 |
| | 2070 Alt Urban High SLR | 0.4 | 0.2 | 4.8 | 3.5 | 3.8 | 2.1 | 0.0 | 1.8 |
| | 2070 Trend Urban Int SLR | 0.4 | 0.2 | 4.0 | 3.2 | 3.0 | 1.8 | 0.0 | 1.8 |
| | 2070 Trend Urban High SLR | 0.5 | 0.2 | 5.3 | 3.7 | 4.1 | 2.2 | 0.0 | 1.8 |
Gopherus polyphemus, red-cockaded woodpecker Picoides borealis, and Sandhill bird index, especially for the gopher tortoise and the Sandhill bird index (brown-headed nuthatch Sitta pusilla, northern bobwhite Colinus virginianus, Bachman’s sparrow Peucaea aestivalis). Projections indicate that urbanization will cause greater losses than SLR for High Pine and Scrub. For the Coastal Uplands Priority Resource, the high SLR scenarios showed the greatest percent loss in area for the conservation targets (Table 3), especially in 2070. Many of the projected Coastal Uplands losses in area from SLR were high, with the greatest at 46.8% projected loss for Ecological Greenways. We determined the mean elevation of Coastal Uplands to be 1.46 m (SD = 1.44 m) by using the U.S Geological Survey (2019) digital elevation model, with the most frequent elevation observed (60.02%) at 0–1 m. The general pattern of a greater loss in area due to urbanization and SLR in 2070 than in 2040 was less pronounced for the Freshwater Aquatics Priority Resource, but still resulted in loss (Table 4). We found a lower percentage of Freshwater Aquatics area lost from future SLR than High Pine and Scrub and Coastal Uplands Priority Resources, with the highest Freshwater Aquatics area lost at 5.3%.

We combined CLIP Priority 1 and 2 percent decrease in area (Tables 2–4) to compare projected losses from high vs. intermediate SLR, holding urbanization constant, for each Priority Resource. Coastal Uplands showed the greatest difference in percent area lost between high and intermediate SLR (Figure 2). The mean difference for all urbanization scenarios in percent area lost between high and intermediate SLR was greatest for Coastal Uplands (mean difference for all urbanization scenarios = 15.03) compared with High Pine and Scrub (mean = 0.13) and Freshwater Aquatics (mean = 0.07). Furthermore, the difference in percent area lost between high and intermediate SLR for Coastal Uplands is slightly greater under the Alternative development scenario (21.12) than under the Trend development scenario (20.83).

Discussion

Our results project increasing losses in extent and area of priority conservation ecosystems moving toward 2070. These findings are attributable to projections of increasing urbanization and SLR over the coming decades. Generally, we found that the greatest losses are projected to be from SLR than urbanization, although largely from impacts to Coastal Uplands. The increase in percent area lost from Coastal Uplands between high and intermediate SLR is projected to be slightly greater under Alternative urbanization than Trend. This difference is potentially because Alternative aims to reduce sprawl; therefore, more habitat remains compared with Trend, and this remaining habitat can be impacted by high SLR.

Florida has experienced many negative impacts from urban development, including destruction and loss of important habitats and ecosystem services such as flood risk reduction (Arnold and Gibbons 1996). Florida had a mandate to limit urban sprawl and minimize negative impacts on the natural environment (Local Government Comprehensive Planning and Land Development Regulation Act of 1985; Frank 1985) but even so, policies were not always adopted at the local level (Brody and Highfield 2005). To protect the environment and restore environmental damage caused by urbanization, Florida enables several options for landowners and developers, such as establishing conservation easements where landowners are paid not to develop land in exchange for reduced taxation or creation of mitigation banks (where the land is used to offset continued development elsewhere). Brody and Highfield (2005) suggest that imposing legal or financial consequences for not adhering to urban planning requirements could lead to greater compliance. In the meantime, scientists, citizens, natural resource managers, and urban planners are increasingly required to innovate alternative solutions to help with the conservation of critical habitats and ecosystems of concern.

For High Pine and Scrub, the projection is for urbanization to cause greater losses than SLR. We found a trend of greater percentage of area projected to be lost for the gopher tortoise and the Sandhill bird index (brown-headed nuthatch, northern bobwhite, Bachman’s sparrow), indicating that these species may be particularly vulnerable to future urbanization. Urbanization has resulted in a greater than 60% reduction in scrub habitat in Florida (Richardson 1989). These areas provide habitat for hundreds of species, many of which are endangered (U.S. Endangered Species Act; ESA 1973, as amended). Gopher tortoise populations, for example, have declined by 80% in the past century due to urbanization and other human development activities that have destroyed their habitat (Diemer 1986). Although managers have developed methods that can support gopher tortoise populations even with dramatically reduced important habitat, for example, by reestablishing summer and winter prescribed burns (Landers and Speake 1980; Russell et al. 1999), these restoration actions are difficult to implement as urbanization and infrastructure encroach on remaining important habitat. Pickens et al. (2017) showed that fire suppression due to urban encroachment was most likely to impact habitat restoration for Bachman’s sparrow. Low-density urban growth (the Trend scenario) has a disproportionate negative impact, per capita, on these species.

Projections suggest that losses for Freshwater Aquatics from urbanization and SLR will be minimal. One explanation is that freshwater has less potential for impact from SLR because of greater distances from the coast and less potential impact from urbanization owing to the challenges of developing on water bodies such as natural lakes, rivers, and streams. The persistence of freshwater wetland ecosystems depends on their ability to keep pace with SLR through soil accretion (Scavia et al. 2002). However, one aspect that our SLR scenarios do not consider is saltwater intrusion into the aquifer. If saltwater intrusion were to carry far into freshwater ecosystems, many of the species that inhabit these ecosystems may not be able to persist (e.g., Nielsen et al. 2003). Depending on hydrologic conditions, saltwater...
intrusion from SLR may range from a few meters to more than a kilometer (Werner and Simmons 2009). Much of Florida has a porous, limestone base, and most of the state is lower than 3.7 m in elevation, with most salt-intolerant communities occurring at less than a 2-m elevation (Saha et al. 2011). In addition, any location in Florida is a maximum of 100 km from the coast, with most locations much more proximal to the state’s extensive coastline; therefore, saltwater intrusion requires serious consideration both for the natural world and for human needs.

With losses up to 46.8% for Coastal Uplands, this low-lying Priority Resource is the most vulnerable to SLR, which is significant because of its importance for Florida’s tourism industry. These coastal ecosystems would benefit from sustainable management to continue to attract tourists that contribute to Florida’s economy. The Florida Keys alone (Figure 1) represent a multibillion-dollar tourist industry including diving, fishing, and snorkeling (Donahue et al. 2008). An examination of potential tourism impacts to 19 of Florida’s neighboring countries in the Caribbean (where tourism contributes 14% to gross domestic product) showed that 29–60% of coastal tourist resort destinations are likely to be partially or fully inundated with 1 m of SLR, and losses greater than 50% in five of these countries (Scott et al. 2012). In Florida, in one year alone, state, local, and federal sources spent $110 million for 19 beach renourishment projects because of their importance to the tourism industry, a cost that is likely to grow with SLR (Klein and Osleeb 2010).

Before 2012, many government agencies entrusted with the protection of natural resources either were not developing or not implementing climate adaptation plans (Archie et al. 2012). Mozumder et al. (2011) surveyed personnel from federal and state agencies, nongovernmental organizations, and other relevant experts in the Florida Keys on climate change and its impacts and found that respondents felt they were making decisions without formal adaptation plans, with a lack of information, and without appropriate institutional frameworks in place to address increasing environmental damage from climate change. Since then, Florida has been proactive about climate adaptation planning, particularly with respect to coastal flooding and SLR. Florida has created “adaptation action areas” [Community Planning Act, Florida Statutes Section 163.3164(1)] in cities and counties throughout the state that are threatened by high water events and are hydrologically connected to coastal waters with the goal of prioritizing funding for infrastructure and adaptation planning for coastal flooding. The Florida Fish and Wildlife Conservation Commission (2016) also released a guide for the conservation and management of Florida’s species, habitats, and ecosystems given predicted impacts from climate change. Depending on how Florida moves forward with implementation of these adaptation strategies that include protecting natural habitats in its coastal regions, planned actions could have major implications not only for natural resources conservation but also for storm surge and flood protection into the future (Geselbracht et al. 2015; Romañach et al. 2018). Although Florida may be farther along than most, a study of adaptation plans from other developed countries highlights shortcomings with preparedness for climate change and minimal plans to implement management actions to reduce vulnerability and suggests integrating adaptation planning as an integral part of urban planning (Preston et al. 2011).

Understanding the future effects of urbanization and SLR on conservation targets is important to aid in conservation planning. Not only are urbanization and SLR affecting land use and conservation planning globally, they are also expected to increase in the future (Nicholls and Cazenave 2010; Wang et al. 2012). Information on the potential extent of future urbanization and SLR can benefit decision makers to help them effectively manage species and habitats of conservation concern.

**Supplemental Material**

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**Reference S1.** Donahue S, Acosta A, Akins L, Ault J, Bohnsack J, Boyer J, Callahan M, Causey B, Cox C, Delaney J, Delgado G, Edwards K, Garrett G, Keller B, Kellison GT, Leeworthy VR, MacLaughlin L, McClanahan L, Miller MW, Miller SL, Ritchie K, Rohmann S, Santavy D, Patterson-Semmens C, Sniffen B, Werndli S, Williams DE. 2008. The state of coral reef ecosystems of the Florida Keys. Pages 161–415 in Waddell JE, Clarke AM, editors. The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73, NOAA/NCCOS Technical Center for Coastal Monitoring and Assessment’s Biogeography Team, Silver Spring, Maryland.

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**Data A1.** Spatial data layer of the High Pine and Scrub Priority Resource from the Peninsular Florida Landscape Conservation Cooperative, clipped to areas of Priority 1 and 2 from the Critical Land and Waters Identification Project 4.0 Aggregated Priorities model.
the University of Florida GeoPlan center. Data layers for Florida’s 36 coastal counties developed by intermediate and high sea level rise paired with six scenarios, which are all possible combinations of Scrub, Coastal Uplands, and Freshwater Aquatics, for scenario modeling for three Priority Resources: High Pine, Freshwater Aquatics Priority Resource.

Data A2. Spatial data layer of the Coastal Uplands Priority Resource from the Peninsular Florida Landscape Conservation Cooperative, clipped to areas of Priority 1 and 2 from the Critical Land and Waters Identification Project 4.0 Aggregated Priorities model.

Data A3. Spatial data layer of the Freshwater Aquatics Priority Resource from the Peninsular Florida Landscape Conservation Cooperative, clipped to areas of Priority 1 and 2 from the Critical Land and Waters Identification Project 4.0 Aggregated Priorities model. The link contains multiple data layers – the raster titled “freshaq_new” is the Freshwater Aquatics Priority Resource.

Data A4. The 1000 Friends of Florida urbanization spatial data layers for the Florida 2060 projections (both development projections and existing urban layers).

Data A5. The 1000 Friends of Florida “Alternative” urbanization layer for the Florida 2070 projections.

Data A6. The 1000 Friends of Florida “Trend” urbanization spatial data layer for the Florida 2070 projections.

Data A7. The 1000 Friends of Florida 2010 baseline urbanization spatial data layer for the Florida 2070 projections.

Data A8. The 2040 and 2070 SLR inundation spatial data layers for Florida’s 36 coastal counties developed by the University of Florida GeoPlan center.

Data A9. Spatial outputs from conservation target scenario modeling for three Priority Resources: High Pine and Scrub, Coastal Uplands, and Freshwater Aquatics, for six scenarios, which are all possible combinations of intermediate and high sea level rise paired with urbanization projections for 2040 and 2070, where 2070 includes sprawling and compact development scenarios.

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References

Archie KM, Dilling L, Milford JB, Pampel FC. 2012. Climate change and western public lands: a survey of U.S. federal land managers on the status of adaptation efforts. Ecology and Society 17(4):20. https://doi.org/10.5751/ES-05187-170420

Arnold CL, Gibbons CJ. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62:243–258.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. 2012. Impacts of climate change on the future of biodiversity. Ecology Letters 15:365–377. https://doi.org/10.1111/j.1461-0248.2011.01736.x

Brody SD, Highfield WE. 2005. Does planning work?: testing the implementation of local environmental planning in Florida. Journal of the American Planning Association 71:159–175.

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naem S. 2012. Biodiversity loss and its impact on humanity. Nature 486(7401):59–67.

Carr M, Zwick P. 2016. Florida 2070: mapping Florida’s future - alternative patterns of development in 2070. Gainesville, Florida, U.S.A. Available: http://1000friendsofflorida.org/florida2070/ (December 2019).

Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, Merrifield MA, Milne GA, Nerem RS, Nunn PD, Payne AJ, Pfeffer WT, Stammer D, Unnikrishnan AS. 2013: Sea level change. Pages X–X in Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, Pages 1137-1216 editors. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, Merrifield MA, Milne GA, Nerem RS, Nunn PD, Payne AJ, Pfeffer WT, Stammer D, Unnikrishnan AS. 2013: Sea level change. Pages X–X in Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, Pages 1137-1216 editors. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York. Available: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf (December 2019).

Department of Environmental Protection. 2011. Sample and use of the Lake Vegetation Index (LVI) for assessing lake plant communities in Florida: a primer. DEP-SAS-002/11. Available: https://floridadep.gov/dear/water-quality-standards-program/documents/lake-vegetation-index-primer (December 2019).

Diemer J. 1986. The ecology and management of the gopher tortoise in the southeastern United States. Herpetologica 42:125–133.

Donahue S, Acosta A, Akins L, Ault J, Bohnsack J, Boyer J, Callahan M, Causey B, Cox C, Delaney J, Delgado G, Edwards K, Garrett G, Keller B, Kellison GT, Leeworthy VR, MacLaughlin L, McClanachan L, Miller MW, Miller SL, Ritchie K, Rohmann S, Santavy D, Pattengill-Semmens C, Sniffen B, Werndli S, Williams DE. 2008. The state of coral reef ecosystems of the Florida Keys. Pages 161–415 in Waddell JE, Clarke AM, editors. The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73, NOAA/NCCOS Center for Coastal Monitoring and Assessment’s Biogeography Team, Silver Spring, Maryland (see Supplemental Material, Reference S1).

Florida Fish and Wildlife Conservation Commission. 2016. A guide to climate change adaptation for conservation - version 1. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida. Available: https://myfwc.com/media/5864/adaptation-guide.pdf (April 2020).

Florida Natural Areas Inventory. 2000. Florida Forever Conservation Needs Assessment: summary report to the Florida Advisory Council. Florida Natural Areas Inventory, Tallahassee, Florida.

Florida Natural Areas Inventory. 2018. Florida Forever Conservation Needs Assessment. Technical report version 4.4. Florida Natural Areas Inventory, Tallahassee, Florida.

Frank JE. 1985. Florida’s local government comprehensive planning and land development regulation act. Land Use Law Zoning Digest 37(8):3–5.

Geselbracht LL, Freeman K, Birch AP, Brenner J, Gordon DR. 2015. Modeled sea level rise impacts on coastal ecosystems at six major estuaries on Florida’s gulf coast: implications for adaptation planning. PLoS ONE 10:e0132079. https://doi.org/10.1371/journal.pone.0132079

Groves CR, Jensen DB, Valutis LL, Redford KH, Shaffer ML, Scott JM, Baumgartner JV, Higgins JV, Beck MW, Anderson MG. 2002. Planning for biodiversity conservation: putting conservation science into practice. BioScience 52:499–512. https://doi.org/10.1641/0006-3568(2002)052[0499:PFBCPC]2.0.CO;2

Hooper DU, Adair EC, Cardinale BJ, Byrnes JEK, Hungate BA, Matulich KL, Gonzalez A, Duffy JE, Gamfeldt L, O’Connor ML. 2012. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature 486(7401):105–108.

Huber M, White K. 2015. Sea level change curve calculator (2015.46) user manual. USACE Responses to Climate Change Program, U.S. Army Corps of Engineers, Washington, D.C. Available: http://corpsmap.usace.army.mil/cccinfo/slic/ccaceslcurves_2015_46.html (December 2019).

Kawula R, Redner J. 2018. Florida Land Cover Classification SystemTallahassee, Florida: Florida Fish and Wildlife Conservation Commission. Available: https://myfwc.com/media/20455/land-cover-classification-revision-2018.pdf (April 2020).

Klein YL, Oseleeb S. 2010. Determinants of coastal tourism: a case study of Florida beach counties. Journal of Coastal Research 26:1149–1156.

Landers I, Speake D. 1980. Management needs of sandhill cranes in southern Georgia. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 34:515–529.

Millsap B, Gore J, Runde D, Cerulean S. 1990. Setting priorities for the conservation of fish and wildlife species in Florida. Wildlife Monographs 111:3–57.

Mozumder P, Flugman E, Randhir T. 2011. Adaptation behavior in the face of global climate change: survey responses from experts and decision makers serving the Florida Keys. Ocean and Coastal Management 54:37–44.

Nicholls RJ, Cazenave A. 2010. Sea-level rise and its impact on coastal zones. Science 328(5985):1517–1520.

Nielsen DL, Brock MA, Rees GN, Baldwin DS. 2003. Effects of increasing salinity on freshwater ecosystems in Australia. Australian Journal of Botany 51:655–665.

Nos S. 2011. Between the devil and the deep blue sea: Florida’s unenviable position with respect to sea level rise. Climatic Change 107:1–16.

Oetting J, Hoctor T, Volk M. 2016. Critical Lands and Resources Team, Silver Spring, Maryland (see Supplemental Material, Reference S1).

O'Connor MI. 2012. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature 486(7401):105–108.

Parmesan C, Yohe G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421(6918):37–42.

Parrish J, Braun D, Unnasch R. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. BioScience 53:851–860. https://doi.org/10.1641/0006-3568(2003)053[0851:awcwws]2.0.co;2

Pickens BA, Marcus JF, Carpenter JP, Anderson S, Taillie PJ, Collazo JA. 2017. The effect of urban growth on landscape-scale restoration for a fire-dependent songbird. Journal of Environmental Management 191:105–115. https://doi.org/10.1016/j.jenvman.2017.01.005

Preston BL, Westaway RM, Yuen EJ. 2011. Climate adaptation planning in practice: an evaluation of
adaptation plans from three developed nations. Mitigation and Adaptation Strategies for Global Change 16:407–438.

Richardson DR. 1989. The sand pine scrub community: an annotated bibliography. Florida Scientist 52:65–93.

Románach SS, Benscoter AM, Brandt LA. 2016. Value-focused framework for defining landscape-scale conservation targets. Journal for Nature Conservation 32:53–61. https://doi.org/10.1016/J.JNC.2016.04.005

Románach SS, DeAngelis DL, Koh HL, Li Y, Teh SY, Raja Barizan RS, Zhai L. 2018. Conservation and restoration of mangroves: global status, perspectives, and prognosis. Ocean & Coastal Management 154:72–82.

Russell KR, DH Van Lear, Guynn DC. 1999. Prescribed fire effects on herpetofauna: review and management implications. Wildlife Society Bulletin 27:374–384.

Saha AK, Saha S, Sadle J, Jiang J, Ross MS, Price RM, Stemberg LSLO, Wendelberger KS. 2011. Sea level rise and South Florida coastal forests. Climatic Change 107:81–108.

Scavia D, Field JC, Boesch DF, Buddemeier RW, Burkett V, Cayan DR, Fogarty M, Harwell MA, Howarth RW, Mason C, Reed DJ, Royer TC, Sallenger AH, Titus JG. 2002. Climate change impacts on U.S. coastal and marine ecosystems. Estuaries 25:149–164.

Scott D, Simpson MC, Sim R. 2012. The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. Journal of Sustainable Tourism 20:883–898.

Terando AJ, Costanza J, Belyea C, Dunn RR, McKerrow A, Collazo JA. 2014. The southern megalopolis: using the past to predict the future of urban sprawl in the Southeast U.S. PLoS ONE 9(7):e102261. https://doi.org/10.1371/journal.pone.0102261

Thuiller W. 2004. Patterns and uncertainties of species’ range shifts under climate change. Global Change Biology 10:2020–2027.

[ESA] U.S. Endangered Species Act of 1973, as amended, Pub. L. No. 93-205, 87 Stat. 884 (Dec. 28, 1973). Available: http://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf (December 2019).

U.S. Census Bureau. 2011. 2011 National survey of fishing, hunting, and wildlife-associated recreation. Suitland, Maryland: U.S. Census Bureau.

U.S Geological Survey. 2019. The National Map—new data delivery homepage, advanced viewer, lidar visualization. U.S. Geological Survey Fact sheet 2019-3032. Washington, D.C.: U.S. Department of the Interior. Available: https://pubs.usgs.gov/fs/2019/3032/fs20193032.pdf (April 2020).

University of Florida GeoPlan Center. 2014. Sea level scenario: sketch planning tool. Gainesville, Florida: University of Florida GeoPlan Center. Available: https://sls.geoplan.ufl.edu/ (December 2019).

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. 1997. Human domination of Earth’s ecosystems. Science 277(5325):494–499.

Walther GR. 2010. Community and ecosystem responses to recent climate change. Philosophical Transactions of the Royal Society B: Biological Sciences 365(1549):2019–2024. https://doi.org/10.1098/rstb.2010.0021

Wang J, Gao W, Xu S, Yu L. 2012. Evaluation of the combined risk of sea level rise, land subsidence, and storm surges on the coastal areas of Shanghai, China. Climatic Change 115:537–558.

Werner AD, Simmons CT. 2009. Impact of sea-level rise on sea water intrusion in coastal aquifers. Ground Water 47:197–204. https://doi.org/10.1111/j.1745-6584.2008.00535.x

Zwick P, Carr M. 2006. Florida 2060: a population distribution scenario for the state of Florida. Gainesville, Florida: Florida Department of Agriculture.