Using scenario planning to evaluate the impacts of climate change on wildlife populations and communities in the Florida Everglades

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It is uncertain how climate change will impact hydrologic drivers of wildlife population dynamics in freshwater wetlands of the Florida Everglades, or how to accommodate this uncertainty in restoration decisions. Using projections of climate scenarios for the year 2060, we evaluated how several possible futures could affect wildlife populations (wading birds, fish, alligators, native apple snails, Southern Leopard Frogs, threatened and invasive species) across the Everglades landscape and inform planning already underway. We used data collected from prior research and monitoring to parameterize our wildlife population models. Hydrologic data were simulated using a spatially explicit, regional-scale model. Our scenario evaluations show that changes in temperature, precipitation, and sea level would significantly alter important ecological functions. All of our wildlife indicators were negatively affected by scenarios with less rainfall and more evapotranspiration. Under such scenarios, habitat suitability was substantially reduced for iconic animals such as wading birds and alligators. Conversely, the increased rainfall scenario benefited aquatic prey productivity and apex predators. Cascading impacts on non-native species is speculative, but increasing temperatures could increase the time between cold events that currently limit expansion and abundance of non-native fishes, amphibians, and reptiles with natural ranges in the tropics. This scenario planning framework underscored the benefits of proceeding with Everglades restoration plans that capture and clean more freshwater with the potential to mitigate rainfall loss and postpone impacts of sea-level rise.

Keywords: Climate Change, Ecosystem Restoration, Habitat-Suitability Models, Hydrologic Disturbance, Wildlife Management, Scenario Planning

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INTRODUCTION

Climate change is a threat to biodiversity and the accelerating rate of change is predicted to have negative effects on wildlife populations and communities that are unable to keep pace (Thomas et al. 2004; Visser 2008; Leadley et al. 2010; Bellard et al. 2012). These effects are compounded when ecosystem resilience is already reduced by other anthropogenic stressors, such as development pressures and resource extraction (Gillson et al. 2013). Already, a myriad of wildlife responses to climate change have been demonstrated. Some of the most common responses are distributional shifts, life-history or phenology changes, decoupling of species interactions, population reductions and extinction, increased disease transmission, and diminished resource availability and habitat loss (Walther et al. 2002; Root et al. 2003; Parmesan 2006; Lawler et al. 2009; Mawdsley et al 2009; Gilman et al. 2010). However, the historically unprecedented rate of change will likely lead to novel ecosystem states, raising the question of whether past responses are a suitable guide to future circumstances.

Both ecosystem and wildlife management require reliable ecological predictions to anticipate future needs under possible future climate scenarios (Clark et al. 2001; Bellard et al. 2012). One approach is to use scenario planning (Peterson et al. 2003; Miller et al. 2007) to develop a range of possible future conditions and then simulate ecological responses to these conditions using habitat-suitability models (HSMs; Hirzel et al. 2006). HSMs focus on the degree to which a habitat can support a population or community and are often used for landscape-scale environmental evaluations (U.S. Fish and Wildlife Service 1981) and quantifying effects of restoration projects on species (Barnes et al. 2006). Despite limitations of these approaches, they are currently the best tools for natural resource managers to anticipate consequences of ecosystem change and develop strategies for mitigating those consequences (Araújo and Peterson 2012; Porzig et al. 2014). Here, we present an example of how scenario planning can be used with ecological models to evaluate how changes in climate could affect wildlife populations, and the implications these changes have for ecosystem restoration. We apply our approach to wildlife in the Florida Everglades, a UNESCO World Heritage Site and target of a multi-billion dollar ecosystem restoration program. The Everglades ecosystem is a good model to illustrate how uncertainty about climate change can be integrated into current planning for restoration (see Pearlstine et al. 2010).

The Florida Everglades is an extensive (~historically 10,000 km^2) but highly modified ecosystem comprised predominantly of freshwater wetlands with interspersed uplands (Figure 1). Hydrology is a primary driver of wildlife population dynamics in Everglades wetlands; however, development and agricultural pressures both in the region and throughout the headwaters in central Florida have resulted in a highly modified hydrologic regime. Water that historically flowed south is largely diverted eastward and westward through a series of canals to the Atlantic Ocean and Gulf of Mexico. Much of the remaining flow is controlled directly by operations decisions regarding the timing and volume of water deliveries. Competing human and wildlife interests have resulted in the majority of the southern portion of the Everglades, including Everglades National Park (ENP), receiving less water than historically, and thus becoming more susceptible to drought, salt water intrusion, and stochastic weather events. Meanwhile, in more central and northern marshes located in the Water Conservation Areas (WCA) and the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR), water is often pooled leading to inundation for long periods. Both increased hydroperiods in this region and increased drought frequency and severity in ENP directly impact wildlife populations throughout the Everglades. Restoration of historical hydrologic conditions is a main target of management in the region, but it is uncertain how climate change will impact restoration and management decisions.

Our goal was to evaluate large-scale, relative patterns of wildlife responses across the Everglades under alternative climate scenarios with increased air temperature, varying rainfall, and associated sea-level rise. Most current climate models are global in scope and capture broad-scale patterns of precipitation and temperature expected with climate change (IPCC 2007). Global scale models are too coarse and offer limited use for ecological forecasting in South Florida because most changes in the Everglades will be realized on finer geographic scales (Obeysekera et al. 2011; Obeysekera et al., this issue). Furthermore, there is no consensus on the effects of climate change on rainfall in this region, but regional rainfall is a critical driver of wetland ecology and wildlife biology in the Everglades (Pearlstine 2010). Regional Everglades ecological models require hydrologic inputs at a scale that is relevant to the scale at which species operate. Therefore, we present a framework to assess climate impacts on wildlife by adjusting conditions observed over the past 40 years based on a range of possible future conditions over the Everglades planning horizon. By comparing simulated wildlife responses across these different scenarios we can begin to anticipate how they may respond to climate change despite the uncertainty in future climate conditions.

We used habitat-suitability models (HSMs) to model responses of important wildlife that are demonstrated indicators of the Everglades ecosystem: small freshwater fishes, wading birds, alligators, apple snails, and amphibians (Doren et al. 2009). Each model uses representation of hydrology appropriate for that species (see sections below) but all are derived directly from the same hydrologic data produced from the climate scenarios (see

Climate Scenarios below) and there is overlap in the categories of hydrologic predictors used (Table 1). Because each model uses a slightly different representation of hydrology, comparisons made across scenarios within each taxa are the easiest to interpret; however, common patterns in responses across taxa help to provide a more comprehensive evaluation of potential climate change effects. In addition, we reviewed potential effects on other key endangered, threatened, and invasive species that are important for managers. We used this information to evaluate our ability to develop management and restoration actions that are likely to increase ecosystem resilience and maintain important ecological functions despite accelerating climate change.

METHODS

Climate Scenarios

The potential effects of climate change on hydrology and restoration in the Everglades were realized through a set of climate scenarios because of uncertainties in climate model projections. These scenarios were developed based on trends in climate projections from General Circulation Models (GCMs) (IPCC 2007) and regionally specific downscaled data. Scenarios were evaluated using an ensemble of models emphasizing model credibility (Obeysekera 2011). Further validation was accomplished using a separate statistically downscaled dataset (Maurer et al. 2007). Based on these methodologies, there is agreement that median climate change in South Florida will involve a temperature increase of 1.5˚ C and an increase or decrease in precipitation by approximately 10%. Four climate scenarios were then chosen to represent likely bounds of possible future conditions in the Everglades. The first scenario (BASE) is a baseline established on current landuse in 2010, which represents contemporary climate conditions in which subsequent scenarios are compared. The second scenario (+ET) simulated a 1.5˚ C temperature increase (by exploiting a simple relationship with evapotranspiration) and an associated 30.5 cm sea level rise. The third (-RF+ET) and fourth (+RF+ET) scenarios simulated the same temperature and sea level rise with a 10% decrease and increase in precipitation, respectively. The effects of these climate scenarios on Everglades environmental conditions were achieved using the South Florida Water Management Model (SFWMM; Obeysekera et al., this issue). The SFWMM is a regional scale model used for Everglades restoration planning that produces spatially explicit hydrologic data at a grid cell size of 3.2 x 3.2 km. Based on relationships between hydrologic parameters and climactic variables, observed hydrologic conditions from 1965 - 2005 were adjusted. These data then served as inputs into our wildlife models. See Obeysekera et al. (2014) in this issue for complete details of the SFWMM development and climate scenarios.

Preparation of the SFWMM scenarios for use with ecological models

Water depth is a critical variable in many Everglades ecological models. The SFWMM is often used to model Everglades hydrology; however, the spatial resolution of 3.2 x 3.2 km is too coarse to capture local heterogeneity that may be important to evaluations of species' habitat. The Everglades Depth Estimation Network Digital Elevation Model (EDEN-DEM, Jones and Price 2007) provides finer resolution topography that is used to calculate water depths at 500 x 500 m resolution used for all wildlife models other than fish. This was achieved by Delaunay triangulation (de Berg et al. 2000) of the SFWMM water stages and then subtracting the interpolated water stage surface from the EDEN-DEM ground elevation values.

Wildlife Responses

Fish

Small fishes (standard length < 8 cm) serve important functional roles in the Everglades food web by linking primary production and apex predators. These fishes, most of which have generation times of approximately one year, are the most abundant vertebrates in this ecosystem and are important food sources sustaining a diversity of predators, including piscivorous fishes, crocodilians, and a variety of wading birds (Gunderson and Loftus 1993; Rader 1999; Davis et al. 2005). Wading birds such as White Ibis (*Eudocimus albus*) and Wood Storks (*Mycteria americana*) are especially dependent on small fishes to sustain large rookeries emblematic of the Everglades (Frederick et al. 2009). A reduction in fish production may result in population declines of many important and iconic species dependent on these animals as prey sources. Density of short-lived small fishes are sensitive to changes in local hydrologic conditions and primary production (Sargeant et al. 2010; 2011); and because of their linkage between the physical environment and top trophic levels, they are a key indicator of the Everglades ecosystem (Trexler and Goss 2009).

The frequency and magnitude of drought disturbance in freshwater marshes limits population recovery time and density of fishes in the Everglades (Trexler et al. 2005). Based on a 10-year time series (1996-2006), Trexler and Goss (2009) parameterized a logistic model to predict native small fish density from the time passed since the end of the most recent drying event (days since drydown, DSD; see also Donalson et al. 2011). This time series spanned both drought and high-water conditions and therefore maximized our ability to quantify the full range of fish responses to hydrologic change. Because of variation in landscape features and hydrology within different regions of the Everglades, logistic models (Equation 1) were fit separately to data from three primary regions: Water Conservation Areas (3A and 3B), Shark River Slough, and Taylor Slough (see Figure 1).

$$\log(TOTFISH + 1) = \frac{K}{\left[1+\left(^{(K-Y0)}/_{Y0}\right)e^{(-r*DSD)}\right]} \qquad \text{Eq. 1}$$

Where r is the growth constant, K is the asymptotic density, Y_0 is the Y intercept, *DSD* is the number of days since the marsh surface last dried, and *TOTFISH* is the total density of small-sized fish (number of individuals per m^2). DSD is the hydrologic model input generated from the climate scenarios. K , r, and Y_0 are parameters estimated from model optimization maximizing fit to the observed data. These logistic models explained the majority of the variation in density of small Everglades fishes (60% - >70%).

Using the logistic equation and parameters in Donalson et al. (2011) (Online Resource 1), we simulated the average small fish densities (m^{-2}/day) at 137 sites across the Everglades landscape routinely sampled for the Comprehensive Everglades Restoration Plan Monitoring and Assessment Plan (CERP-MAP). Site selection was determined using a generalized recursive tessellated grid (Stevens and Olsen 2003). We used our CERP-MAP sites because we could down-scale the 3.2 X 3.2 km SFWMM hydrologic output to reflect known local-scale topographical variation at 400 X 400 m resolution relevant to fish densities at these sites. To evaluate the effects of potential climate change on fish densities we calculated the absolute and percent difference in average fish densities between the baseline (BASE) and each of three future climate scenarios.

American Alligator

The American alligator (*Alligator mississippiensis*) plays a key role in Everglades wetlands as both a top predator and an ecosystem engineer (Mazzotti et al. 2009). They alter landscape structure by creating trails and small ponds called alligator holes. These areas may serve as dry season refugia for aquatic fauna or foraging grounds for species that feed on aquatic fauna (Campbell and Mazzotti 2004; Palmer and Mazzotti 2004). In addition, alligator holes contribute to floral and faunal diversity and richness in the wetlands (Campbell and Mazzotti 2004; Palmer and

Mazzotti 2004). Distribution of alligator holes is related to hydrologic variables (Brandt et al. 2010). Fujisaki et al. (2012) report that alligator holes are scarcer in wetlands where modified hydrologic conditions causes dry-downs that may be too frequent or not frequent enough. Lower abundance of alligator holes indicates decreased alligator activities, and may be associated with lower overall species diversity and lack of dry-season aquatic refugia for other organisms.

Hydrology is a main driver of alligator ecology; however, temperature also plays a role in the slower growth rates and smaller sizes of alligators in the Everglades compared to other areas (Mazzotti and Brandt 1997). Higher temperatures result in higher metabolic costs and increased energy demands. Warmer temperatures coupled with changes in hydropattern that alters habitat and prey availability (Loftus et al. 1990) have the potential to negatively impact Everglades alligators. Salinity also plays a role in alligator distribution and relative density. Alligators occur primarily in freshwater marshes, but were once abundant in Everglades estuaries where salinities were low (Mazzotti and Brandt 1994). Throughout the alligator's range nesting is reduced in areas where salinities are greater than 10-12 psu (McNease and Joanen 1978; Wilkinson 1983).

We used a spatially explicit alligator habitat suitability model developed for evaluation of Everglades restoration hydrologic alternatives (see Shinde et al. 2013) to examine potential responses to hydrologic and salinity changes simulated under the SFWMM climate scenarios. The Alligator Production Suitability Index model (APSI) estimates mostly hydrologic factors with higher index scores (0 to 1) reflecting better habitat conditions for hatchling production. Temperature and precipitation changes are not explicit variables in the model; however, the model incorporates changes to hydrologic timing and water depths from temperature, precipitation, and evapotranspiration reflected in the SFWMM scenarios. There are five discrete component indices that combine to produce the final APSI (Table 2). To produce hatchlings (production), alligators must have (1) suitable habitat (H) identified as marsh and marsh-upland edge. (2) Have experienced environmental conditions prior to mating that are conducive to breeding (breeding potential; BP). Water depths > 122 cm reduce food availability and may increase physiological stress (Barr 1997; Dalrymple 1996a; Dalrymple 1996b). In addition, water depths < 15 cm limit the ability of alligators to move easily around the marsh (Mazzotti and Brandt, personal observation) decreasing both access to food and mates (Rice et al. 2004a). (3) Have conditions that allow them to mate (courtship and mating; CM). Throughout the alligator's range, bayous, canals, and deeper water areas of lakes and ponds are the preferred areas for breeding (Newsom et al. 1987). Rice et al. (2004a) reported optimal depth for courtship and mating between 40 cm and 49 cm based on a regression analysis of nest estimates and adjacent slough water depths. (4) Have suitable nest sites (nest building; NB). In constructing nests, alligators are obliged to locate them so that the eggs will be above the seasonal high water level, while remaining near enough to the water's edge to prevent desiccation and providing suitable nursery habitat for young (Mazzotti and Brandt, 1994). Fleming (1990, 1991) reported that nest numbers declined rapidly in Shark Slough (ENP) when marsh water depths exceed 45 cm during the peak nest construction (mid-June/early July). Most alligator nests in ENP are marsh nests located in water less than 25 cm deep (Ogden, 1976). (5) Finally, they should not have their nests flood (nest flooding; NF). The bottom of a clutch can range from about 15 to 30 cm above the water surface depending on whether the nest is built on an elevated area such as a tree island (unpublished data for WCA 2 and 3 cited in Rice et al. 2004a; Kushlan and Jacobsen, 1990 for ENP; and Brandt and Mazzotti, 2000 for LNWR). Kushlan and Jacobsen (1990) reported that within a clutch eggs form layers that total 16.9 ± 4.9 cm thick (N = 181). These five components are expressed as probabilities and because each is essential, they have equal weight in the APSI. The APSI score at each 500 x 500 m output cell and for each year of the SFWMM interpolated inputs is the unweighted geometric mean of the five component scores (Equation 2).

$$APSI = \{P(H) * P(BP) * P(CM) * P(NB) * [1 - P(NF)]\}^{1/5} \qquad \text{Eq. 2}$$

Because the SFWMM hydrologic scenarios do not provide salinity outcomes, the US Geological Survey BISECT model, which models sea level rise (Wang et al. 2007) was used as the salinity input. The salinity output from the BISECT 30.5 cm sea level rise scenario was used as a conservative input of salinity change in the alligator model for the SFWMM climate alternatives. The alligator model was restricted to output from 1996 through 2002 to match the dates available from the BISECT model.

Wading Birds

Wading birds are highly mobile top predators that serve as vital indicators of the Everglades ecosystem, integrating productivity across trophic levels and over a large landscape scale (Frederick et al. 2009). The primary limitation to their reproductive output is the annual production and seasonal availability of food, determined by temporal and spatial variation in rainfall and water management (Gawlik 2002). Because wading birds respond behaviorally to extreme variability in the quantity, quality, and availability of their food resources, models of their distributions can be used to assess the effects of these transient conditions.

Additionally, changes in long-term habitat quality and prey availability have disparately affected wading bird species with a more constrained niche (i.e., specialists; Herring et al. 2010; Beerens et al. 2011). Populations of wading bird species that are tactile foragers and require higher prey concentration (e.g., White Ibis and Wood Stork) have disproportionally decreased from the 1930s to 2001 across the Everglades when compared with populations of visual foragers that favor deep water (e.g., Great Egret; Crozier and Gawlik 2003). In addition, the White Ibis and Wood Stork, while similar in foraging strategy, differ in other traits such as prey size selection, foraging flight distance, nest initiation date, and nest cycle length (Frederick and Ogden 1997) and therefore serve unique functions as indicators.

We used a species-specific, spatially-explicit foraging conditions model (SFC) developed for evaluating hydrologic scenarios for Everglades restoration (Beerens et al. 2013) to examine potential changes in Great Egret, White Ibis, and Wood Stork abundance under the SFWMM climate scenarios. The SFC used Systematic Reconnaissance Flight (SRF) wading bird distribution data, collected monthly from Jan-May, 2002-2009, to pair foraging observations with Everglades Depth Estimation Network (EDEN) depth values. From these depth values SFC calculated water recession rate, days since drydown (DSD), reversal, hydroperiod, and x-y positions that corresponded to the date and cell of use throughout the greater Everglades. Hydrologic variables (i.e., cell characteristics) were then averaged over each instance. Frequency was obtained by counting the number of times over the study period that a species used a given cell. Foraging observations were grouped over time to integrate spatial dynamics unaccounted for by hydrology (e.g.., spatial correlation). By capturing patterns in the spatial variation of the landscape through radial smoothing, the noise independent of the hydrologic parameters can be reduced to better capture the species-specific behavioral response to rapidly changing habitat conditions (Dormann 2007).

Interaction terms among depth, recession rate, and DSD quantified a common trade-off in aspects of prey availability to birds; the tendency of the wetland system to produce prey through spatial immigration and reproduction over long periods of inundation (>6 months; DeAngelis et al. 2005) versus the shorter term (1-2 week) tendency of prey to become concentrated into pools and shallow areas through drying trends. These modifiers are important model inputs because wading birds show increasing selection for the shorter-term process of concentration to mitigate the loss of productive foraging habitat from a shorter period of inundation (Beerens et al. 2011). Therefore, the effect of each resource on frequency of use was expected to vary based on resource levels at differing temporal scales.

Final models predicting frequency of cell use from hydrologic and spatial characteristics were developed using generalized linear mixed models (Proc Glimmix; SAS Institute). This procedure can incorporate parametric variables (e.g., hydrology) and a non-parametric radial smoother (e.g., coordinates) to fit semi-parametric models that account for spatial correlation (McCarter and Burris 2010). A set of *a priori* candidate models tested hypotheses at varying temporal scales and with differing interactions and were evaluated for parsimony using Akaike's Information Criterion with bias correction for small sample sizes (AIC_c; Burnham and Anderson 2002) (Online Resource 2). When output from this model is averaged over the landscape, it can serve as a surrogate measure of the abundance of high-quality patches, demonstrating an increase to a maximum when the greatest area is within a species' suitable depth range, and a decrease as the landscape dries. To evaluate the effects of potential climate change on wading bird distributions, we calculated the percent change in average frequency of cell use, during the breeding months of Jan-May, between the baseline (BASE) and each of three SFWMM climate scenarios.

Apple Snail

Apple snails (*Pomacea paludosa*) are the primary food source for the federally-listed endangered Everglades snail kite (*Rostrhamus sociabilis plumbeus*). Snail kites feed almost exclusively on apple snails (Sykes 1987). Snail kites are not found in areas that lack snails in high enough densities to meet their foraging requirements (Darby et al. 2012). To ultimately understand snail kite population dynamics, a spatially explicit, size-structure model of apple snails (EverSnail; DeAngelis et al. 2011) was developed to examine the potential future for the kite's prey under alternative restoration plans for the Everglades.

EverSnail was developed for use in Everglades restoration planning and is being used as an Ecological Planning Tool for the Central Everglades Planning Process (CEPP). The purpose of the model is to describe the dynamics of the apple snail population as a function of their main population drivers; hydrology and temperature. The population density and size distribution of snails is simulated and can be calculated for any day of a year for which there is relevant input data on hydrology and temperature. The density of adult snails during a given year depends in part on egg production, and therefore environmental conditions from the previous year. We modeled responses of adult snails (> 20 mm) because this is the typical size of snails consumed by snail kites (Sykes 1987).

Amphibians

The role of amphibians in the Everglades ecosystem is as both predators (Ugarte et al. 2007) and as a prey base for iconic Everglades taxa such as wading birds (Casler et al. 2004). The occurrence of amphibians throughout the landscape is dependent on both hydrologic and habitat (vegetation) conditions. Aquatic-breeding amphibians require water in which to lay eggs that develop into larvae. Each species of frog and toad has a unique set of hydrologic requirements ranging from never drying through a year to being wet for only a small portion of the year. Our habitat variables describe vegetation composition and structure (which provides foraging substrate) and refuge from predators (which determines exposure to abiotic conditions such as salinity, temperature and humidity).

An amphibian occurrence model was developed using hydrology and habitat to explain species occurrence while simultaneously accounting for imperfect detection (Waddle and Romañach 2012). Amphibian observation data was taken throughout the Everglades from inventories conducted by the U.S. Geological Survey (Rice et al. 2004b, Rice et al. 2005). Parameter estimates from the occupancy model as well as water depth and habitat (categorized as hammock, pineland, prairie, slough, and swamp) were used to predict amphibian occurrence across the landscape. The habitat input remains static throughout the model period. The results of the model can be viewed as a community response (species richness) or as individual species (response variable). To more closely examine species responses to potential climate change impacts on hydrologic conditions in the region, we will focus on model results for a common amphibian, the Leopard Frog (*Lithobates sphenocephalus*).

Threatened, endangered, and non-native species

We generally lack models of threatened, endangered, or non-native species for use in scenario comparisons; however, much is known about the environmental tolerances and impacts on these species. We provide short reviews of information that provides qualitative insight into climate change impacts on these taxa.

RESULTS

Fish Density

Small fish densities simulated under the BASE climate scenario were highest in the marshes of WCA-3A along the western margins of the L-67 canals, often between 13.8 – 17.15 fish m^{-2} (Online Resource 3a). In the WCA region, fish densities were lowest in 2A. Fish densities were lower on average within ENP than WCA, but within ENP generally highest in SRS (10.44 – 13.79 fish m^{-2}). TSL had the lowest simulated fish densities in ENP (<3.71 fish m^{-2}). Fish densities changed in direction and magnitude under the climate scenarios relative to BASE (Figure 2). When conditions were altered to reflect a 1.5˚ C temperature increase (+ET), decreased water depths from evapotranspiration led to drought increases which reduced fish densities throughout the Everglades system, with the largest decreases in WCA-3A and 3B (% change $^{-}53.3$ - $^{-}63.1$; Online Resource 3b). The same pattern held in the scenario with a 1.5˚ C increase and a 10% decrease in precipitation (-RF+ET); however, the fish density declines were often in excess of $^{-}67$% and as high as $^{-}96.8$% compared to the BASE scenario (Online Resource 3c). In the last scenario, which accounted for a temperature increase and a 10% increase in precipitation (+RF+ET), fish densities generally increased by approximately 5% in SRS, SMP, habitat margins west of L-67 canals in WCA-3A, and the southern portion of LNWR (Online Resource 3d). In the remainder of the Everglades marshes, fish densities increased between 5% and 36%. Taylor Slough was the only region where fish densities were predicted to increase in all three scenarios (Table 3).

Sea level rise only affected the southern reaches of Taylor Slough in the area we modeled by lengthening hydroperiods in areas otherwise receiving reduced freshwater. Raises in salinity in this area will favor estuarine fishes over the freshwater fish fauna, similar to conditions currently observed in the dry season further south in the same area (Lorenz 1999; Lorenz and Serafy 2006). Lorenz and Serafy (2006) found that the estuarine fish assemblage supported lower biomass than the freshwater assemblage, leading to diminished prey availability for wading birds. However, the model-predicted lengthened hydroperiod may counteract some of the expected negative effect on fish productivity of switching from a freshwater to an estuarine fish community.

American Alligator

All three scenarios result in reduction in total area classified as *Most suitable habitat* (index ≥ 0.8; Figure 3). Loss of *Most suitable habitat* was highest in the +RF+ET scenario (26%, 74 km^2) and lowest in the -RF-ET scenario (10%, 29 km^2) and varied geographically. Spatially modeled BASE conditions show low suitability for alligator production in the northern areas of LNWR, WCA-2A, and WCA-3 primarily because conditions are too dry (Online Resource

4a). In some areas, primarily adjacent to canals and levees (L-67 for example), suitability is low because it is too wet. Reduction in water depths and hydroperiods from increased evapotranspiration (+ET) worsens suitability in localized areas of northern WCA-3, but improves suitability along levees and in the south/southwest portion of WCA-3 (Online Resource 4b). Lower rainfall and higher evapotranspiration (-RF+ET) further reduces suitability in WCA-2, northern WCA-3 and northern LNWR. (Online Resource 4c). In southern WCA-3, patterns of habitat suitability shift, resulting in an increase of 48 km^2 of *Most suitable habitat* along the western margins of the L-67 canals, where water was deeper under the BASE scenario. An increase of rainfall and evapotranspiration (+RF+ET) results in suitability distributions similar to BASE conditions; however, increased water ponding in the southwest reduces suitability in that area relative to BASE conditions (Online Resource 4d).

In ENP, habitat in the central slough (Shark River Slough) is good for alligator production under the BASE climate scenario. The spatial extent of *Most suitable habitat* in the slough is reduced by 43 km^2 with increased evapotranspiration (+ET) and reduced by 80 km^2 with decreasing rainfall and increasing evapotranspiration (-RF+ET). Under the +RF+ET scenario, increased rainfall mitigates increased evapotranspiration and alligator suitability has a similar distribution to the BASE conditions.

Wading Birds

The SFC models indicate that a spatial cell is used more frequently by all species when DSD increases and depth is shallow; increased prey density (from many DSD; see *Fish*) is further concentrated into shallow depths (Beerens et al. 2013). Longer hydroperiods also increase cell use. Rapid recession rates play a particularly important role for Great Egrets and to a lesser extent White Ibis by maintaining high cell frequency when DSD is low. Higher recession rates are more important for Great Egrets feeding in shallower depths and White Ibis feeding in deeper depths, likely better accommodating their opposing foraging strategies.

Across all bird species, there was a slight negative response to the +ET scenario and a slight positive response to the +RF+ET scenario (relative to BASE; Figure 4). Under –RF+ET scenario, drier conditions have a negative impact on the foraging response of all wading bird species (Online Resources 5-7); particularly the Great Egret and Wood Stork which typically use deep water habitats. Additionally, any water loss through evapotranspiration or reduced rainfall lowers landscape DSD, hydroperiods, and resulting prey production, such that prey density is not as high when depths are shallow.

Apple Snail

Compared to the BASE scenario, an increase of 1.5˚ C with no change in rainfall (+ET) does not suggest negative consequences to snail populations (Figure 5; Online Resource 87). Apple snail populations appear to be most negatively impacted by climate changes that result in an overall decrease in average rainfall. Increased average rainfall (+RF+ET) has some positive impacts on the snail population compared to BASE, particularly in the northern and southern ends of the model domain. Previous simulations have shown significant declines in population size when water depth was too high during the main reproductive period, which can negatively impact egg laying and egg survival (Darby et al., *personal communication*), but the 10% increase of +RF+ET suggests overall positive impacts on snail populations.

Amphibians

Model output for the leopard frog show that scenarios of +RF+ET and +ET compare similarly, spatially and temporally, to BASE, but -RF+ET leads to decreased probability of occurrence in WCA-3A and -B and ENP (Figure 6; Online Resource 9).

Threatened & Endangered Species:

Climate envelope models provide insight into potential impacts of climate change on the distributions of Florida's threatened and endangered vertebrates (Watling et al. 2012). The models describe species occurrences using current temperature and precipitation experienced throughout the species range and can be used to forecast suitable climate space for a species under climate projections. Models have been run on global climate projections (Watling et al. 2012) as well as both statically and dynamically down-scaled climate projections for Florida (Bucklin et al. 2013). Four of the species considered in the aforementioned studies that occur in the Everglades are: Florida panther (*Puma concolor coryi*), Everglade Snail Kite, Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*), and American crocodile (*Crocodylus acutus*).

Among the variables most associated with species presence, precipitation in the months of May, September, and October were common to all four species (Bucklin et al. 2013). In South Florida, these months are associated with the onset of the wet season (May) as well as the peak of the wet season (Sep/Oct). Changes in precipitation (+RF+ET, -RF+ET) during these months could have negative impacts on these species adapted to the hydrologic regime of the Everglades. Also, Florida's endangered subspecies tend to have lower adaptive capacities and lower dispersal capabilities than parent species (e.g., Florida panther vs. cougar) (Benscoter et al. 2013) which suggest an uncertain future for these species following unfavorable changes in climactic conditions. Panthers tend to be less active when water levels or temperatures are high (Janis and Clark 2002). Therefore, the +RF+ET scenario could have the most negative impacts on panthers because it would lead to both higher water levels and higher temperatures. Snail Kites could experience range expansion with increased precipitation (+RF+ET) as apple snail populations expand. Decreased precipitation (-RF+ET) could lead to greatly reduced snail populations and likely a subsequent reduction in Snail Kite population size. Increased temperatures could lower apple snail populations if increases are too high, though the scenarios considered here (+RF+ET, -RF+ET, +ET) do not suggest decreased future apple snail population sizes based on a 1.5˚ C temperature increase. Changes in precipitation would likely have greater impacts on the Cape Sable Seaside Sparrow compared to temperature change. Nesting is typically completed before the onset of the wet season (Lockwood et al. 1997) and high water conditions may lead to decreased nesting attempts or unsuccessful nesting.

Changes in temperature and precipitation in the Everglades may have mixed effects on American crocodiles. Crocodiles, like many species in the Everglades, are sensitive to timing of freshwater delivery (Mazzotti et al. 2009; Cherkiss et al. 2011). Both desiccation and flooding can lead to unsuccessful nesting (Mazzotti 1989), suggesting that changes in precipitation during the nesting season could have negative impacts on the species by increasing ground water levels and hence the probability that a nest would flood. However, warmer temperature would allow the American crocodile to nest earlier in the year, as they do in the rest of their range. Earlier nesting would avoid higher water levels of the wet season and could decrease the probability that a nest would flood. Effects of changes in ground water levels brought about by changes in precipitation are likely to be overwhelmed by a sea level rise of 30.5 cm which would flood much of the existing natural nesting habitat for American crocodiles in Florida. There is anecdotal evidence that some natural nesting sites for crocodiles in Florida already have succumbed to rising sea level (Mazzotti et al 2007). Crocodile nests on higher elevation canal berms will be less affected by rising sea level (Mazzotti et al. 2007). In addition, growth and survival of hatchling crocodiles is inversely influenced by fall water salinities (Mazzotti et al. 2007; Mazzotti et al. 2009) which are determined by rainfall and water delivery. Therefore, increases in salinity due to diminished rainfall would also negatively impact crocodiles.

Invasive Species:

Pyron et al. (2008) and Rodda et al. (2008) modeled possible invasion extent of Burmese pythons (*Python molurus bivittatus)* in the Everglades and in other parts of the USA based on climatic suitability and incorporated climate-change scenarios. Their results differed greatly in predicting invasion extent under current and climate change scenarios. Mazzotti et al. (2010) evaluated the effect of an extreme cold event on Burmese pythons. After prolonged exposure to low temperature, 9 of 10 telemetered pythons died when ambient temperatures fell below 5˚ C. While it is tempting to say an increase in average temperature would increase the extent of invasion by pythons, that would not be the case if an increase in average temperature was accompanied by an increase in the frequency of extreme cold temperature events. Scenarios that increase the amount of open water and increase salinity also could impact pythons. Hart et al. (2012) found that hatchling Burmese pythons were fairly tolerant of salt water. Given that larger reptile species are generally more tolerant of exposure to salt water than hatchlings (Dunson and Mazzotti 1989), salinity increases may not prove to be a barrier to range expansion by pythons. Telemetry studies being analyzed now may shed light on preference or avoidance of open water by pythons; however, pythons have been observed swimming in Everglades National Park, including one in Florida Bay (Skip Snow, National Park Service, *personal communication*).

Predicted occurrence modeling results under the –RF+ET scenario show an expansion of habitat suitable for occurrence of Cuban tree frogs (*Osteopilus septentrionalis*) and greenhouse frogs (*Eleutherodactylus planirostris*), particularly at the southern end of their range. This scenario tends to be detrimental to other taxa in the Everglades, but may promote the spread of invasive species that are not native to the unique hydrologic conditions of the Everglades.

Thirty-three species of non-native freshwater fish have become established in Florida since the 1950's; 17 in the Everglades (Kline et al. 2013). All of these species are tropical in their distribution (Loftus 2000) and northern expansion is believed to be limited by annual temperature minima (Shaflan and Pestrak 1982; Trexler et al. 2000). There is no reason to expect rising temperatures of the magnitude in our scenarios to adversely affect non-native freshwater fish in the Everglades. However, periodic extreme winter low-temperature events that currently limit non-native freshwater fish may be less common in warmer scenarios, leading to release of non-native species. For example, a cold-season event in 2010 led to local decline or extinction of non-native fishes, that have since recovered (Kline et al. 2013; Rehage et al. 2013). The absence of such events in a warmer climate could enhance the spread of the current non-native taxa. Our models of native small fish suggest that their abundance will be compromised by drier future scenarios. It is possible that these conditions could favor species better adapted to cope with drying conditions. The Asian swamp eel (*Monopterus albus*) is an invading species with highly developed adaptations for tolerance of anaerobic conditions and ammonia that permit it to burrow in mud to survive drying conditions in their native range (Ip et al. 2004). There is currently no evidence that a greater frequency of drying will favor such species over native taxa, but it is a possibility. The impacts of current non-native species appear to be spatially restricted (Trexler et al. 2000; Harrison et al. 2013). Climate change within the bounds of our climate scenarios increases the uncertainty of non-native species impacts and distributions in the future.

DISCUSSION

The life blood of the Everglades is water. Many species are tightly tied to the hydrologic cycle and are therefore vulnerable to changes in climate that affect availability of water. We show that scenario planning is useful in the context of the Everglades where climactic drivers have strong effects on wildlife, but the extent of these effects is uncertain. In this case, we used scenarios that were produced by adjusting historical records using climactic conditions representing likely bounds of temperature and precipitation states expected under climate change in 2060. Using wildlife and habitat-suitability models, we demonstrate that key indicator species of the Everglades may be susceptible to the range of changes in temperature, precipitation, and sea-level rise associated with the climate change scenarios over the Everglades restoration planning horizon. The scenario with a 1.5˚ C temperature increase and 10% reduction in precipitation was predicted to have the largest negative effects on ecological performance of native species. This may be the most likely future scenario from the set because recent regionally downscaled models suggest peninsular Florida will experience warmer year round conditions with reduced mean summer precipitation (Selman et al. 2013). An increase in temperature without a change in precipitation was detrimental, to a lesser extent, for most species. Increasing rainfall mitigated negative effects from increasing temperature and was predicted to be slightly beneficial for most species.

Threatened and endangered vertebrates are expected to have lower tolerance for changes in climactic conditions and therefore may be especially vulnerable to climate change, while establishment of non-native species may be facilitated. Southern Florida has proven particularly vulnerable to invasion as a result of being the center of the pet trade (both locally cultured and imported) and a welcoming subtropical climate. Reports (Krysko et al. 2011) identified 137 species of non-native reptiles and amphibians introduced into Florida; 56 were characterized as reproducing. Between 2000 and 2012, eight new species of freshwater fishes appeared in Everglades National Park (Kline et al. 2013). Changes in temperature and precipitation may increase the risk for further invasion and establishment by non-native species with impacts that are difficult to anticipate.

It is important to interpret these results in the context and assumptions of the climate and wildlife models. Because of large uncertainties forecasting regional climate in South Florida, the projections represent likely bounds of mean conditions. Increasingly, however, forecasts for climate change in the southeastern US predict more intense precipitation events separated by longer, more extreme droughts (Li et al. 2011; Selman et al. 2013). This increase in weather extremes may have greatest impacts on wildlife that rely on historical hydrological cycles to initiate breeding or dispersal behavior. Decoupling biological responses from these environmental cues may lead to greater negative impacts than predictions based on mean conditions. All wildlife in the Everglades would likely be affected by such outcomes, with especially large effects on colonial wading birds (Pearlstine et al. 2010). The fish models explicitly consider drought severity to predict population recovery times and densities; however, the impact of increased disturbance frequency may have emergent effects on recovery patterns that can't be predicted from time since disturbance alone. In addition, non-stationarity in the relationships between climate and wildlife drivers could also lead to deviations from predictions based on observed historical conditions. Therefore, the responses we demonstrate may be best case scenarios because future conditions will likely be more variable than historical conditions in which the models were parameterized. Persistent monitoring efforts will eventually allow us to understand how such extremes alter model parameters. Because these modeling efforts are relatively flexible, we can update parameter estimates and uncertainties or incorporate model structural changes as information becomes available.

Although there is uncertainty in both the climate scenarios and the wildlife models the results provide hypotheses of where our greatest challenges and opportunities may be in responding to climate change. For example, examination of the spatial patterns of habitat suitability under the different scenarios shows which areas may be affected more or less for each species. The areas that repeatedly show up with large negative changes in habitat suitability across species are ones that might warrant more focused attention and discussion on what management is feasible to minimize negative impacts. Despite uncertainty in future conditions, we can now begin to anticipate consequences of climate change for wildlife populations and communities.

This scenario-based modeling framework has also highlighted the need for additional analyses to supplement our understanding of potential wildlife responses. For example, knowledge of species tolerances throughout their life cycle to new temperature regimes, and their effect on species turnover rates and interactions, is completely lacking. Also, changes in water conditions associated with climate change will likely affect landscape connectivity and ecosystem size. Explicit consideration of the resilience or susceptibility of wildlife to temporal and spatial dynamics in ecosystem connectivity could aid in identification of habitat areas or corridors in most critical need of restoration action or protection. Some spatially explicit modeling efforts have incorporated behaviorally based movement rules to model wildlife dynamics at the landscape scale (e.g., Yurek et al. 2013), but these models have been challenging to balance landscape realism and model complexity. Other promising approaches to model climate effects on local and regional connectivity patterns include Graph theory (Minor and Urban 2007; McIntyre et al. 2014) and Circuit theory (McRae et al. 2008). By combining predictions from multiple approaches we may begin to better understand geographic areas in the landscape where predictions yield greater consensus and areas where predictions are most uncertain (Diniz-Filho et al. 2009).

Ultimately, to buffer the Everglades ecosystem and wildlife from the effects of climate change, ecosystem-based management strategies that increase resilience are needed (Pearlstine et al. 2010). Drought disturbance and drier conditions were the most important cause of decreased suitability and production of wildlife through most of the ecosystem. Over longer time horizons than considered for this project (>50 years) sea-level rise may alter the environment more conspicuously, especially in the southern edge of the ecosystem at the interface with Florida Bay. One management priority that is recommended to mitigate these effects is to increase deliveries of freshwater into marshes and coastal wetlands (Pearlstine et al. 2010). Increased freshwater flows could increase resilience of the ecosystem by reducing drought disturbance frequency and severity; buffering the marshes from stochastic weather events expected to increase under climate change. In addition, increased freshwater flows are expected to minimize saltwater intrusion associated with sea-level rise (Karamperidou et al. 2013. Future studies should more explicitly quantify how such factors can influence ecosystem resilience and how this may mitigate the effects of climate change on wildlife populations and communities. In addition, development of early warning indicators, generic (Dakos et al. 2012) or model-based (Ives and Dakos 2012), should be incorporated with ongoing wildlife monitoring programs to detect critical tipping points in ecosystem states before they are reached.

Potential management strategies to be implemented as part of Everglades restoration must have adaptive capacities (Walters and Hilborn 1978; U.S. Army Corps of Engineers 2004). Climate change is a continual process; as such, ecosystem management targets will also shift as climate changes are realized. As environmental parameters respond to changes in climactic conditions, wildlife that can track such changes will likely shift habitat use and distributions. Such an outcome will alter community structure and species interactions and can lead to wildlife responses that could not be predicted from prior relationships (Beckage et al. 2011). Therefore, an essential component of adaptive management is continual monitoring programs that document such changes. These programs are ultimately needed to produce and calibrate new models to predict wildlife responses. Updated climate scenarios are also necessary as regional projections are refined. This framework of scenario planning, adaptive management, wildlife monitoring, and early warning indicators could increase our capacity to manage the Everglades ecosystem and wildlife despite uncertainties in climate change.

A primary concern among the public and natural resource managers is the role or validity of restoration actions in the face of climate change. This study highlights that infrastructure and restoration actions increasing freshwater flows into the Everglades ecosystem are even more critical than ever to maintain important ecological functions and prevent instability in a rapidly changing climate. In addition, this exercise has helped identify potential gaps in our knowledge about how the system and its wildlife inhabitants will respond to such changes. The Everglades is an extensive and intensively managed ecosystem. The scenario planning approach we present may be useful for managers of other ecosystems to determine possible ecological effects of climate change and to identify current gaps in abilities to anticipate and manage for such changes.

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ETHICAL STANDARDS

All research presented in this article comply with the laws and ethical standards of the United States of America and all entities and agencies represented by the authors. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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TABLES

Table 1. Ecological model inputs summarized for each taxonomic group investigated under the different climate scenarios.

Taxon	**Model Inputs**						
	Days since dry	Water depth	Change in water depth	Duration of depth	Salinity	Temperature	Habitat
Fish	X						
Wading birds	X	X	X	X			
Alligator		X	X	X	X		X
Apple Snail		X				X	
Amphibians				X	X		X

Table 2. Summary of components in the alligator production suitability index. The annual breeding cycle and the relevant timing of each component is covered under "Evaluation period".

Component Index	**Variables**	**Evaluation period**
Habitat	Proportion of area within each cell that is suitable land cover for alligator habitat	NA, static input
Breeding potential	Joint proportion of days that are either too dry or too wet	April$_{i-1}$ 16- April$_i$ 15
Courtship and mating	Average water depth, Presence of alligator holes	April$_i$ 16- May$_i$ 31
Nest building	Average water depth, Presence of alligator holes, Presence of upland edge, Salinity	June$_i$ 15- July$_i$ 15
Nest flooding	Average and standard deviation water depths during nest building period, Maximum water depths during nest flooding period, Presence of upland edge	July$_i$ 01- Aug$_i$ 31

i refers to current year and ***i-1*** refers to previous year

Table 3. Percent change in Average Fish Density between baseline conditions (BASE) and each of the climate scenarios: +ET, -RF+ET, +RF+ET. Differences are calculated for each region: Water Conservation Areas 2A, 3A, and 3B, The Loxahatchee National Wildlife Refuge (LNWR), Shark River Slough (SRS), Taylor Slough (TSL), and Southern Marl Prairie regions of Everglades National park.

Region	+ET	-RF+ET	+RF+ET
WCA-2A	-17.17	-38.74	5.36
WCA-3A	-20.26	-70.14	7.03
WCA-3B	-20.47	-67.42	5.29
LNWR	-12.35	-38.76	3.81
SMP	-13.63	-31	5.96
SRS	-16.84	-42.32	5.58
TSL	45.21	20.46	82.03

FIGURES

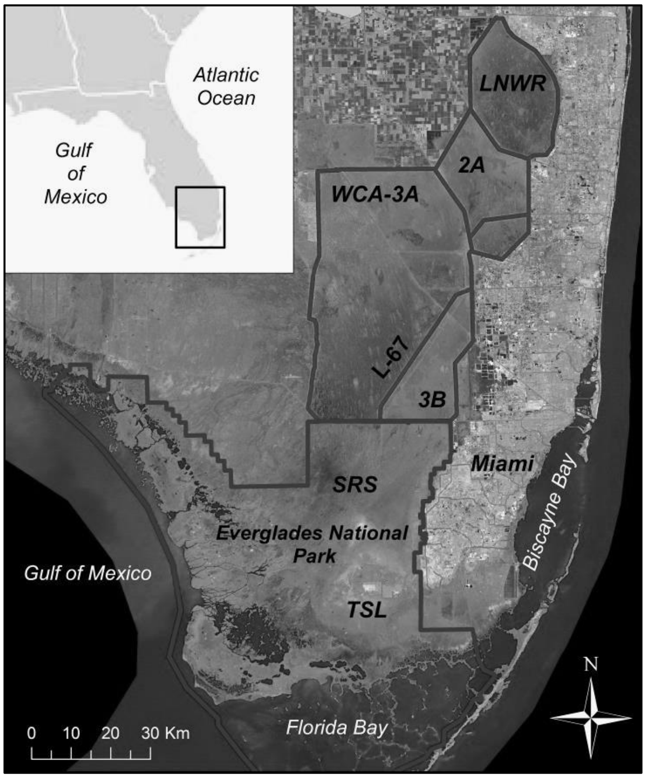


Fig 1 Map of southern Florida and model domain. Everglades National Park (ENP) includes Shark River Slough (SRS) and Taylor Slough (TSL). Water Conservation Areas (WCA) include the Loxahatchee National Wildlife Refuge (LNWR) and WCA-2A, -3A, and -3B

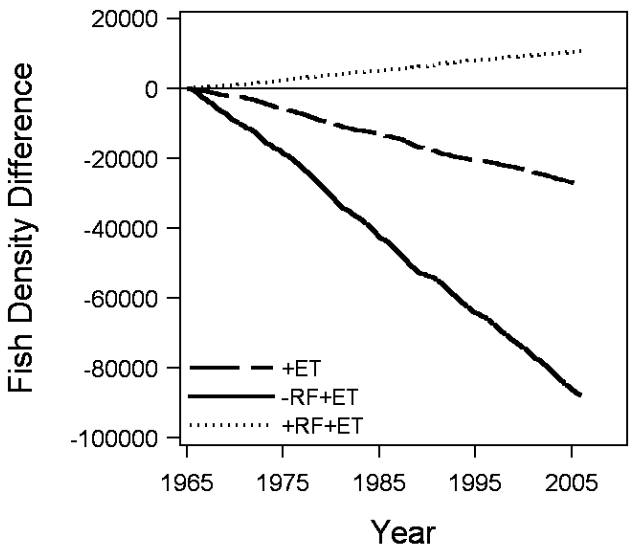


Fig 2 Cumulative difference in mean fish density (fish per m^2) across the Everglades predicted under each climate scenario relative to the baseline scenario. +ET represents scenario with increased evapotranspiration associated with 1.5˚ C temperature increase, -RF+ET represents scenario with 10% decrease in rainfall and increased evapotranspiration, and +RF+ET represents scenario with 10% increase in rainfall and increased evapotranspiration

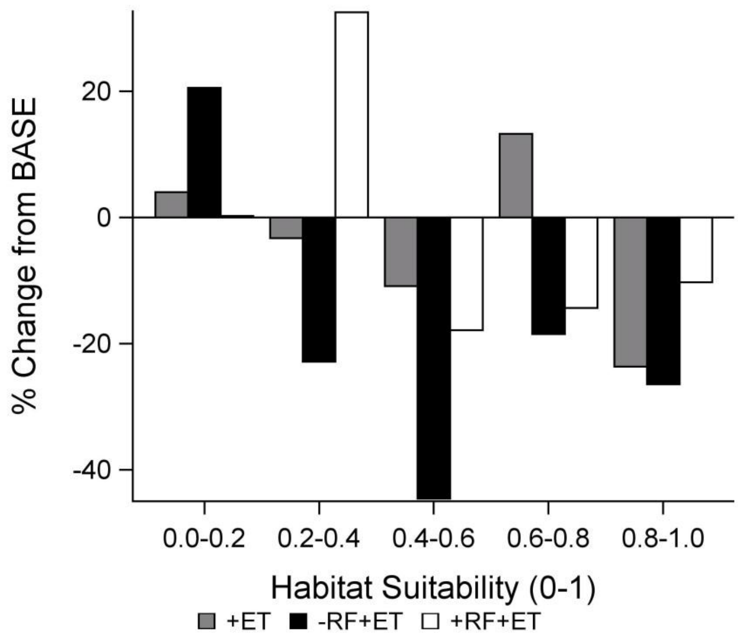


Fig 3 Percent change from the baseline scenario (BASE) to alternative future climate scenarios (+ET, -RF+ET, +RF+ET) in median 1996-2002 Alligator Production Suitability Index scores for LNWR, WCA-2, WCA-3, and ENP combined

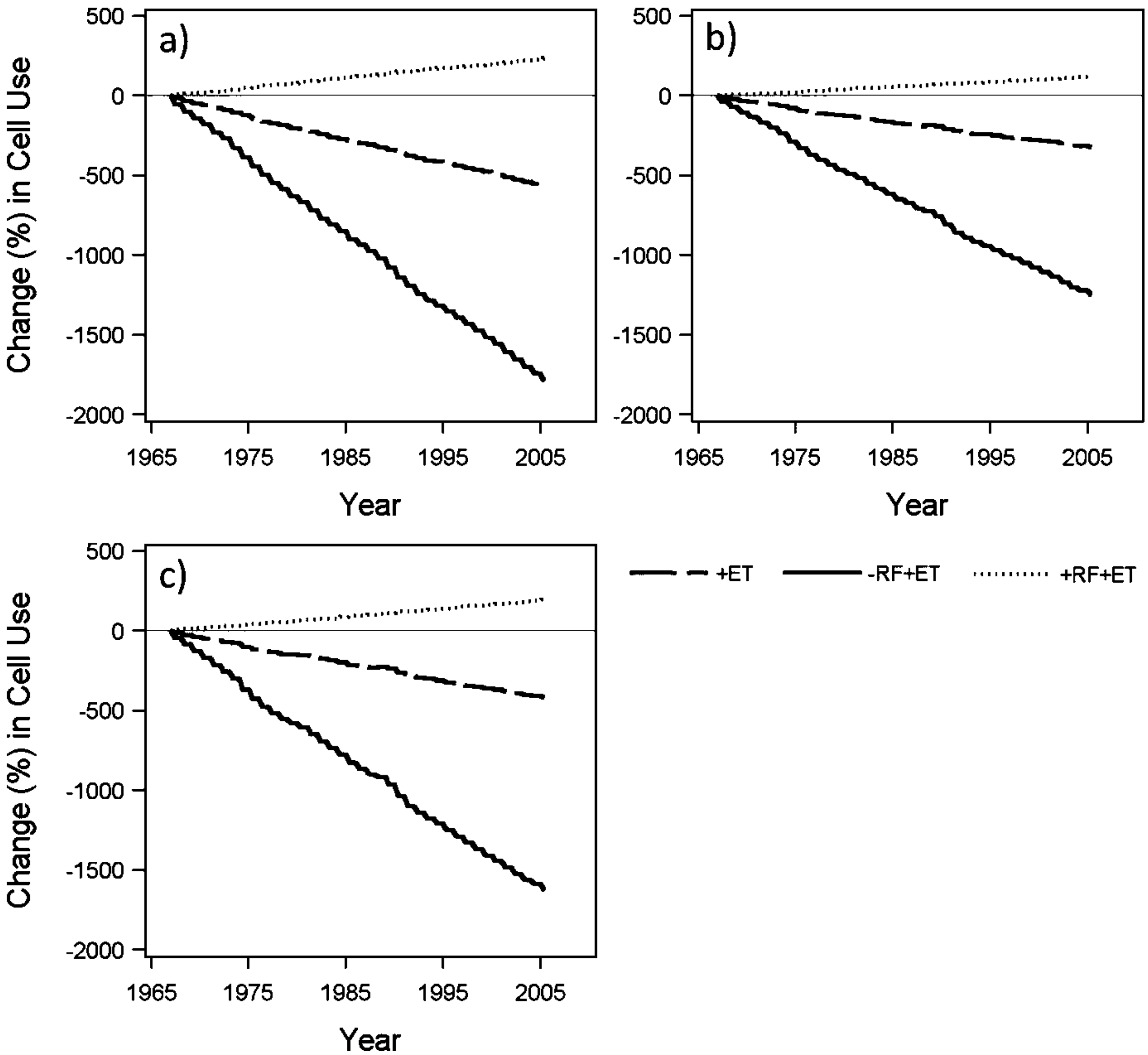


Fig 4 Cumulative mean percent change in a) Wood Stork, b) White Ibis, and c) Great Egret cell use simulated under future climate scenarios +RF+ET, +ET, and -RF+ET, relative to the baseline during the breeding months of Jan-May, 1967-2005

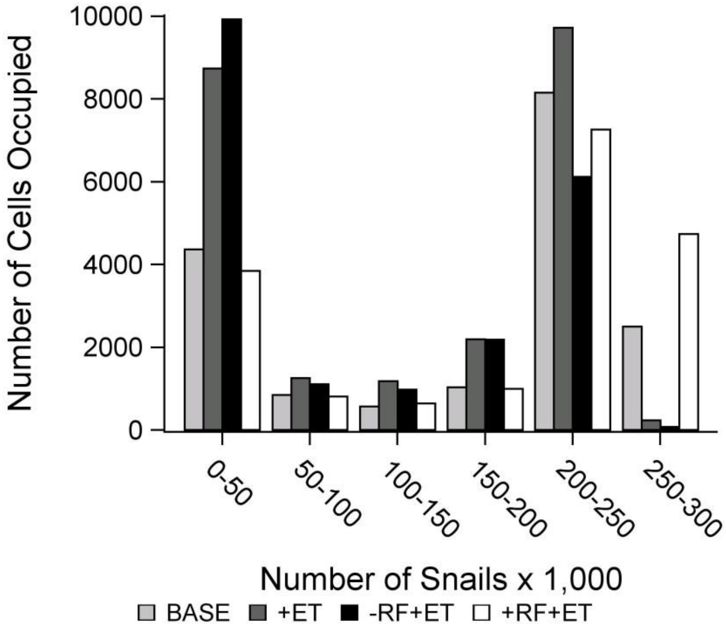


Fig 5 Number of 500 m^2 model cells corresponding to the number of apple snails (in thousands) predicted under each climate scenario (BASE, +RF+ET, +ET, and -RF+ET). +RF+ET produced the most model cells with the highest snail density, while the –RF+ET scenario produced the most cells with the lowest density of snails

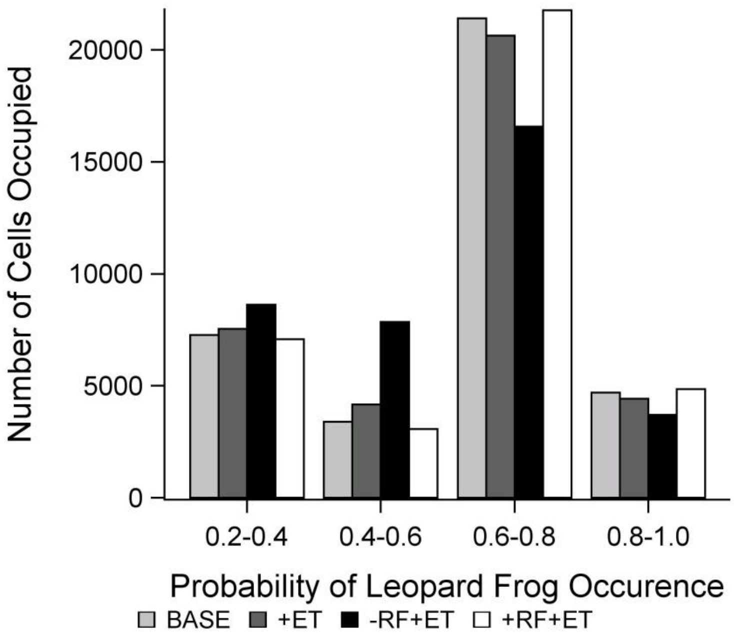


Fig 6 Number of 500 m^2 model cells corresponding to the probability of leopard frog occurrence predicted under each climate scenario (BASE, +RF+ET, +ET, and -RF+ET). Most scenarios were comparable; however, –RF+ET demonstrated a shift in cells from the second highest suitability category (0.6-0.8) to the second lowest (0.4-0.6)

Online Resource 1. Parameter estimates and associated standard errors (SE) derived from logistic model predicting total fish density, ln(y+1), from days since the site was last dry (DSD) for three primary hydrologic regions of the Everglades: Water Conservation Areas (WCA), Shark River Slough, and Taylor Slough.

	WCA		**Shark River Slough**		**Taylor Slough**	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE
K	2.901	0.0192	2.757	0.1499	2.625	0.0640
r	0.097	0.0114	0.006	0.0003	0.003	0.0635
Y0	0.300	0.1639	1.486	0.0577	1.080	0.0005

Online Resource 2. Details and fit statistics of models used to predict wading bird cell use for Great Egrets, White Ibis, and Wood Stork. Sample size (N), AICc, model ID, change in AICc (Δ AICc), model weight (w), coefficient of determination (R^2), average parameter estimate (Avg PE), standard error (SE) and variable importance are reported.

GREAT EGRET MODEL	N	AICC	ID	Δ AICc	w	R^2
Depth, Depth^2, Recess^2, DSD^2, HP, Reversal, Depth*DSD, Depth*Recess, Recess*DSD	**12**	**3167.9**	**5**	**0.00**	**0.42**	**0.86**
Depth, Depth^2, Recess^2, DSD^2, HP, Reversal, Depth*DSD, Depth*Recess	11	3168.5	11	0.63	0.31	
Global	16	3168.8	1	0.86	0.27	

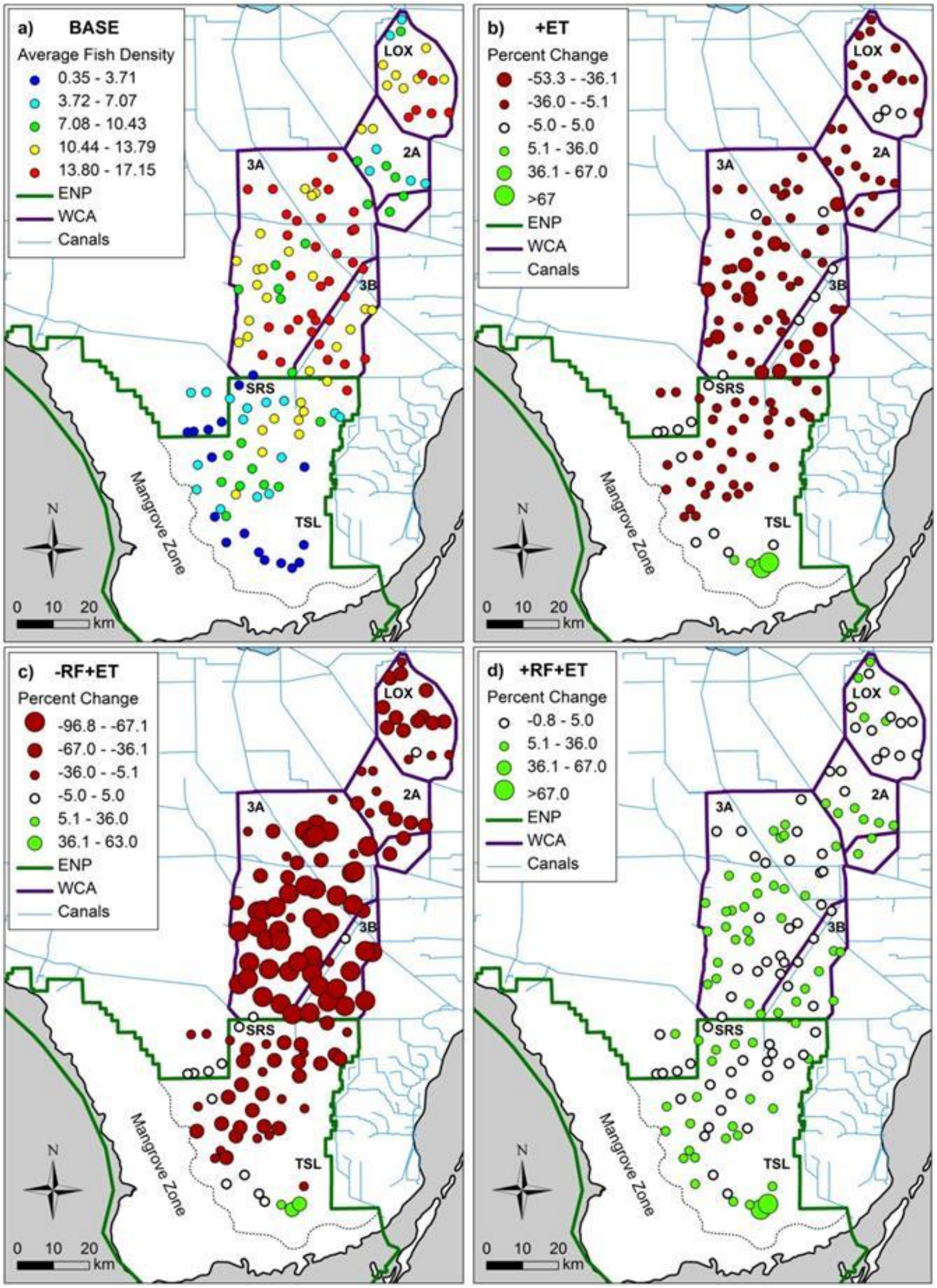
Variable	N	Avg PE	SE	Importance
Intercept	**27**	**0.4694**	**15.38**	**1.00**
Depth	**15**	**-0.0073**	**0.00**	**1.00**
Depth^2	**15**	**-0.0005**	**0.00**	**1.00**
Recess^2	**10**	**-0.0473**	**0.03**	**1.00**
DSD^2	**14**	**-3.25E-6**	**0.00**	**1.00**
HP	**14**	**0.0071**	**0.00**	**1.00**
Reversal	**16**	**-0.3044**	**0.09**	**1.00**
Depth*DSD	**15**	**0.0001**	**0.00**	**1.00**
Depth*Recess	**14**	**-0.0062**	**0.00**	**1.00**
Recess*DSD	**12**	**0.0003**	**0.00**	**0.71**

WHITE IBIS MODEL	N	AICC	ID	Δ AICc	w	R^2
Depth, Depth^2, Recess^2, DSD, DSD^2, HP^2, Depth*DSD, Depth*Recess, Recess*DSD	**12**	**3235.6**	**11**	**0.00**	**0.60**	**0.81**
Depth, Depth^2, Recess^2, DSD, DSD^2, HP^2, Reversal, Depth*DSD, Depth*Recess, Recess*DSD	13	3236.8	18	1.28	0.31	
Global	16	3239.2	1	3.66	0.10	

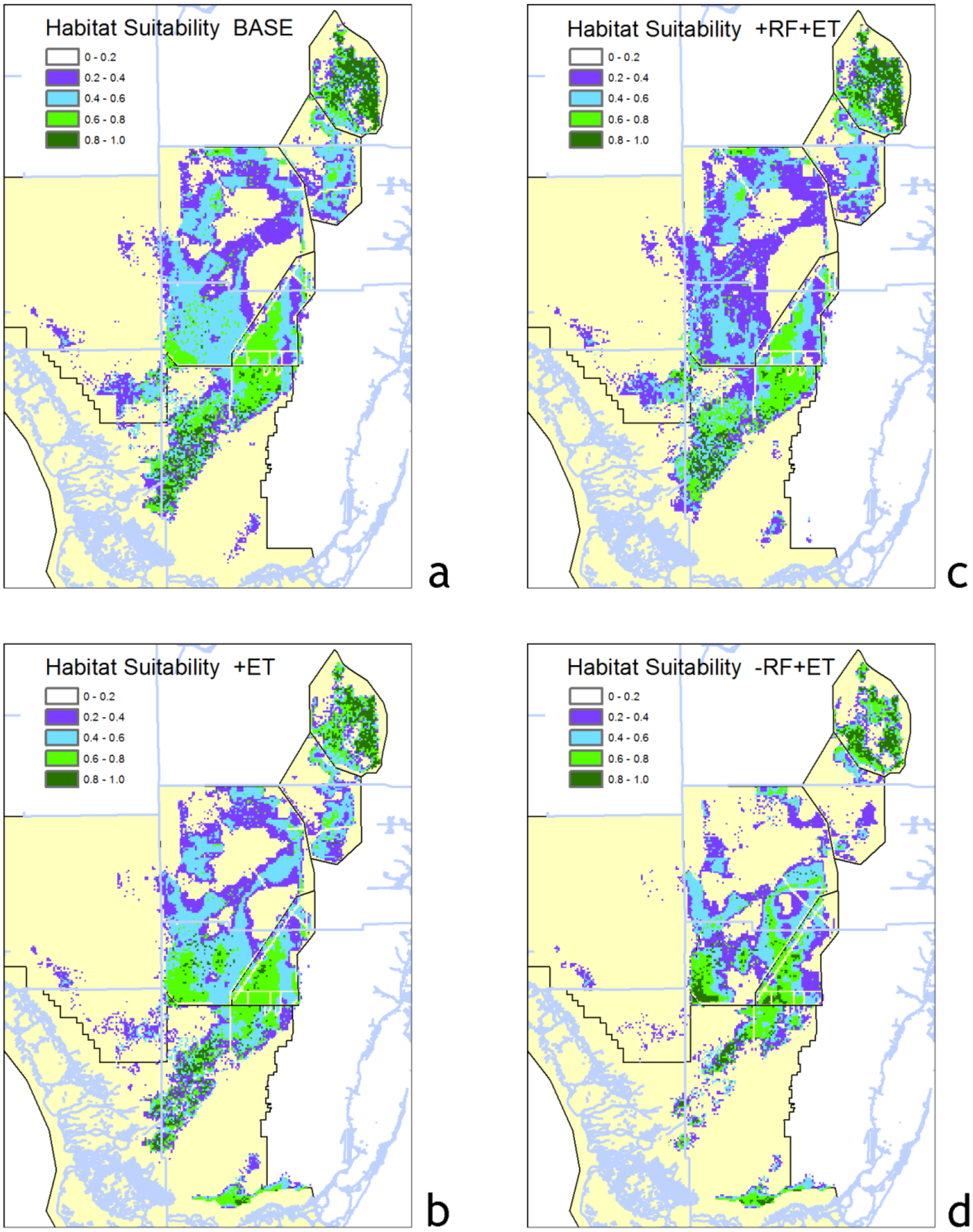
Variable	N	Avg PE	SE	Importance
Intercept	**27**	**-0.0891**	**14.84**	**1.00**
Depth	**15**	**-0.0171**	**0.00**	**1.00**
Depth^2	**15**	**-0.0004**	**0.00**	**1.00**
Recess^2	**10**	**-0.0647**	**0.02**	**1.00**
DSD	**13**	**0.0026**	**0.00**	**1.00**
DSD^2	**14**	**-5.12E-6**	**0.00**	**1.00**
HP^2	**8**	**9.66E-6**	**0.00**	**1.00**
Depth*DSD	**15**	**0.0001**	**0.00**	**1.00**
Depth*Recess	**14**	**-0.0040**	**0.00**	**1.00**
Recess*DSD	**13**	**0.0004**	**0.00**	**1.00**

WOOD STORK MODEL	N	AICC	ID	Δ AICc	w	R^2
Depth, Depth^2, DSD, DSD^2, HP, HP^2, Reversal, Depth*DSD	**12**	**1810.0**	**12**	**0.00**	**0.81**	**0.56**
Depth, Depth^2, DSD, DSD^2, HP, HP^2, Reversal, Depth*DSD, Depth*Recess, Recess*DSD	15	1813.6	18	3.53	0.14	

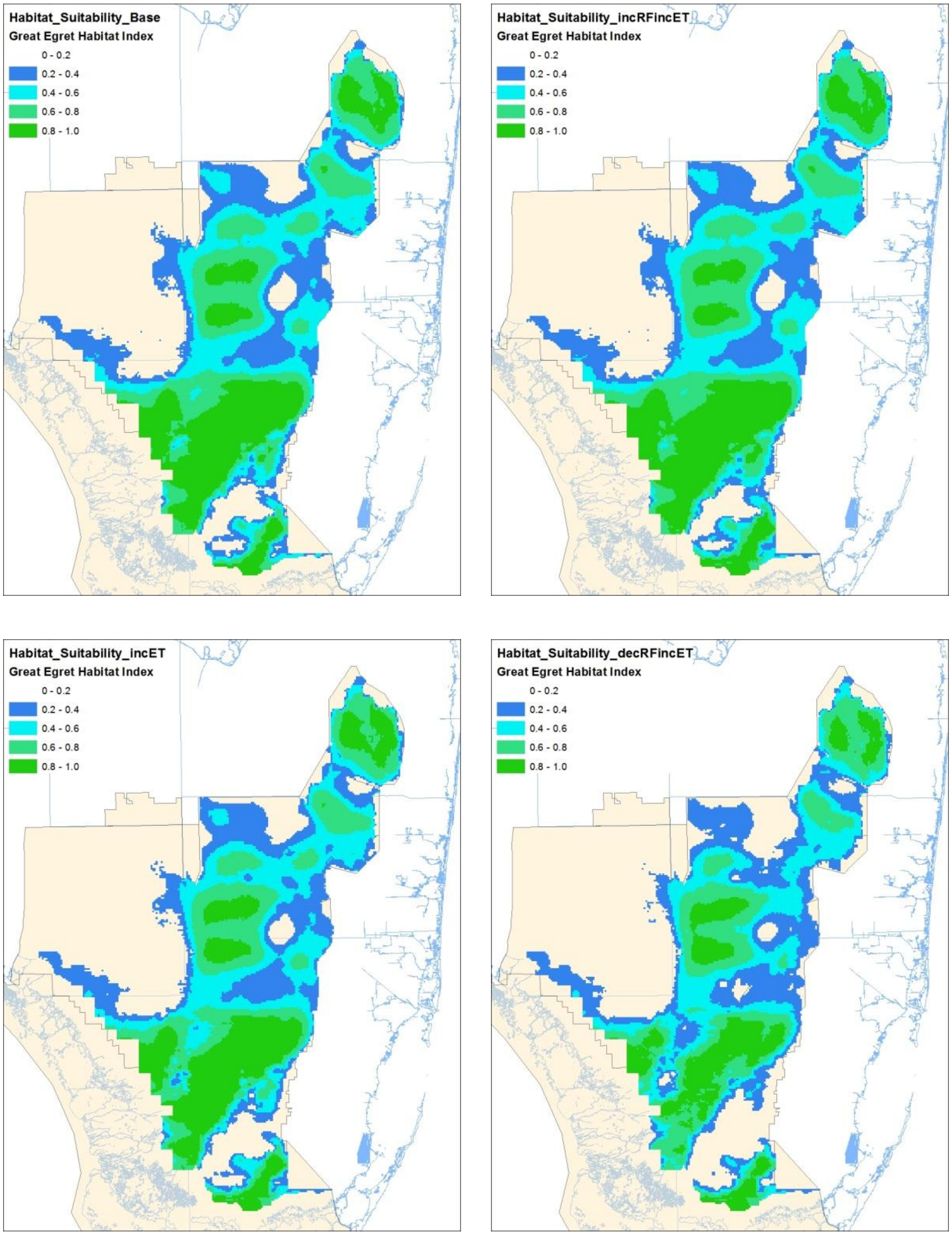
Variable	N	Avg PE	SE	Importance
Intercept	**27**	**-0.1963**	**0.86**	**1.00**
Depth	**15**	**-0.0120**	**0.00**	**1.00**
Depth^2	**15**	**-0.0003**	**0.00**	**1.00**
DSD	**13**	**0.0030**	**0.00**	**1.00**
DSD^2	**14**	**-4.19E-6**	**0.00**	**1.00**
HP	**13**	**-0.0056**	**0.00**	**1.00**
HP^2	**9**	**2.33E-5**	**0.00**	**1.00**
Reversal	**13**	**0.2645**	**0.09**	**1.00**
Depth*DSD	**15**	**4.10E-5**	**0.00**	**1.00**



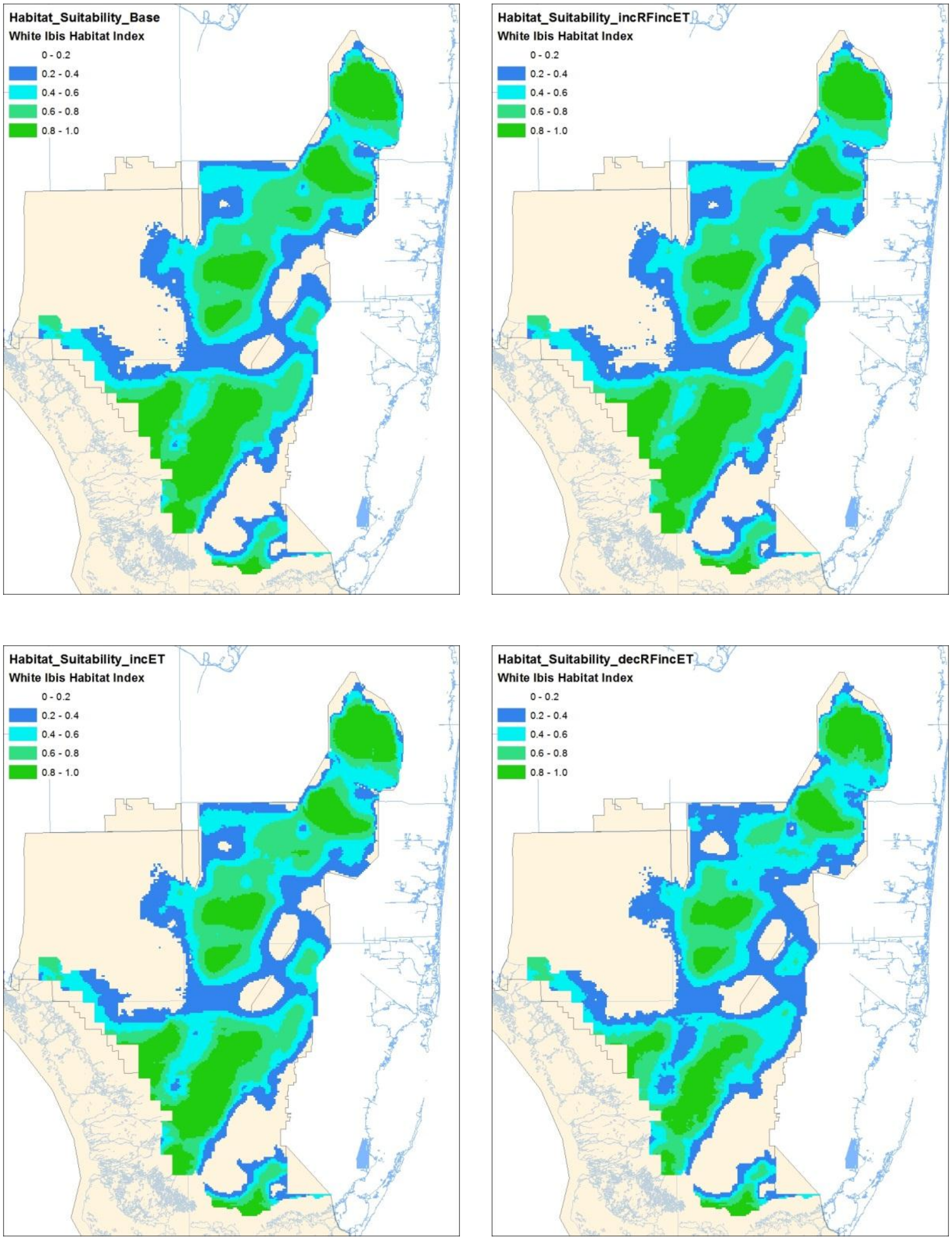
Online Resource 3. Spatial distribution of fish densities and percent change from BASE to each climate scenario: a) Average fish density predicted under BASE (m^{-2}), the percent difference between BASE and a) increased evapotranspiration (+ET), c) decreased rainfall and increased evapotranspiration (-RF+ET), and d) increased rainfall and increased evapotranspiration (+RF+ET). Note southern sites in TSL region increased hydroperiod in all scenarios because of sea level rise. See text for discussion



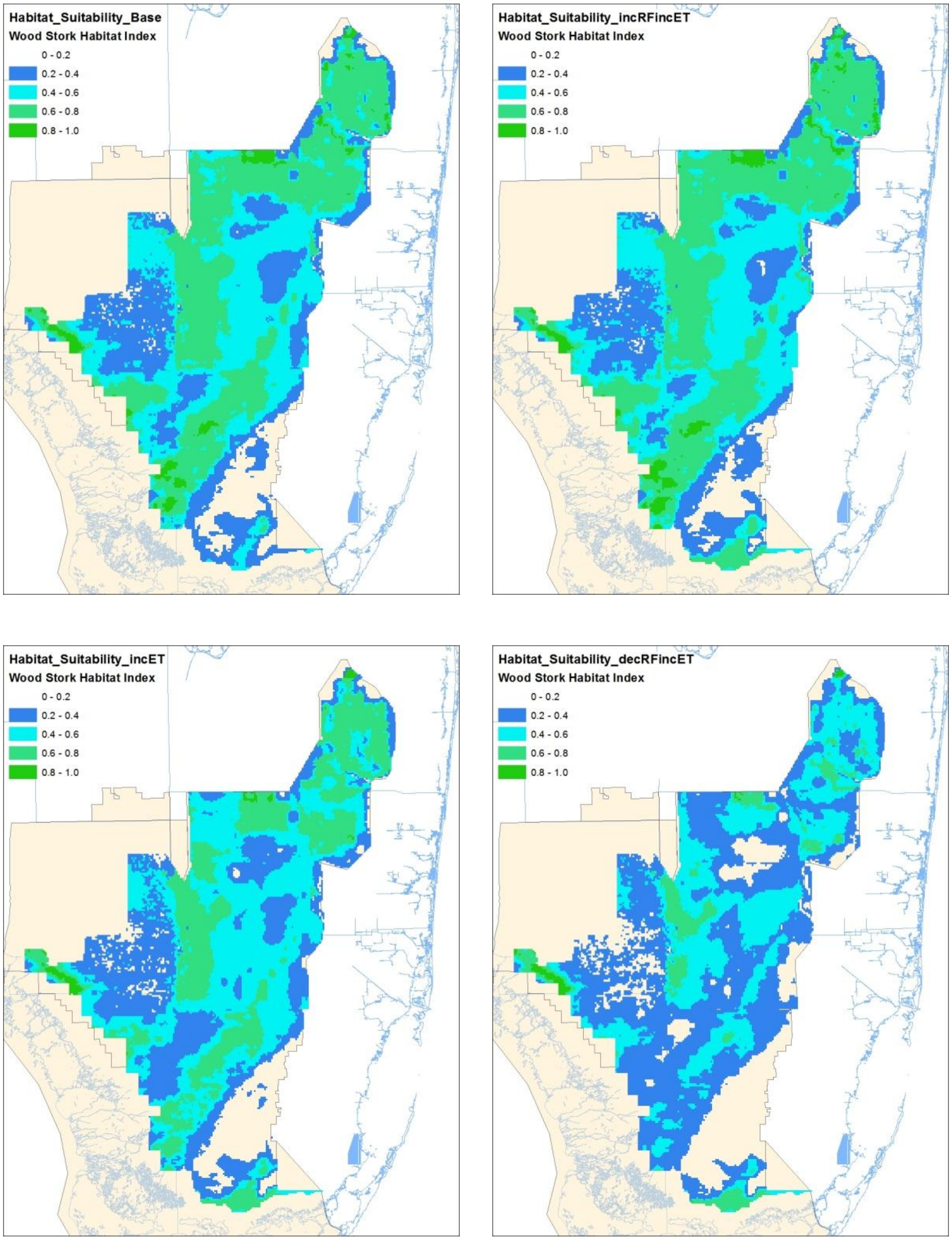
Online Resource 4. Median 1996-2002 Alligator Production Suitability Index scores for 4 climate scenarios: a) BASE, b) +ET, c) -RF+ET, and d) +RF+ET. See text for discussion



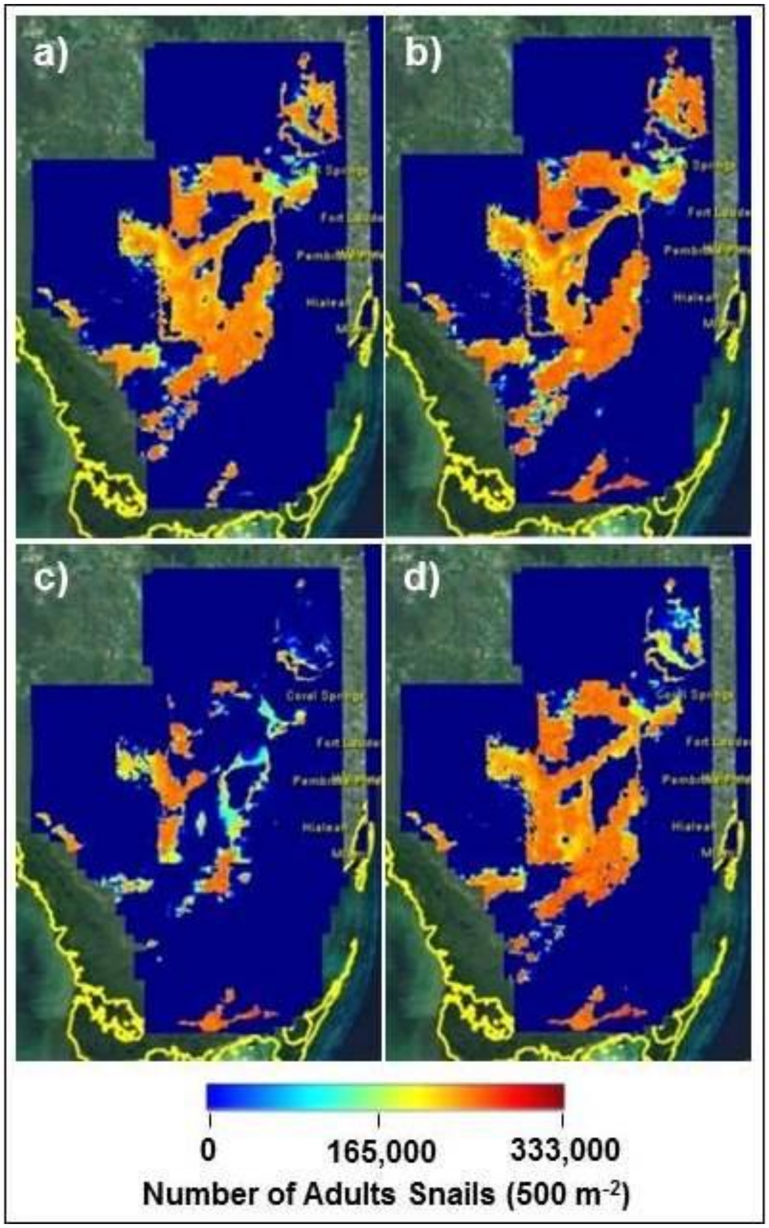
Online Resource 5. Predicted mean Great Egret habitat suitability maps (1967-2005) for 4 climate scenarios (clockwise: BASE, +RF+ET, -RF+ET, +ET). Dark green represents the highest frequency of use, whereas dark blue represents the lowest. The area of high-quality habitat is reduced with decreasing modeled rainfall, with the largest loss occurring in the -RF+ET scenario. See text for discussion



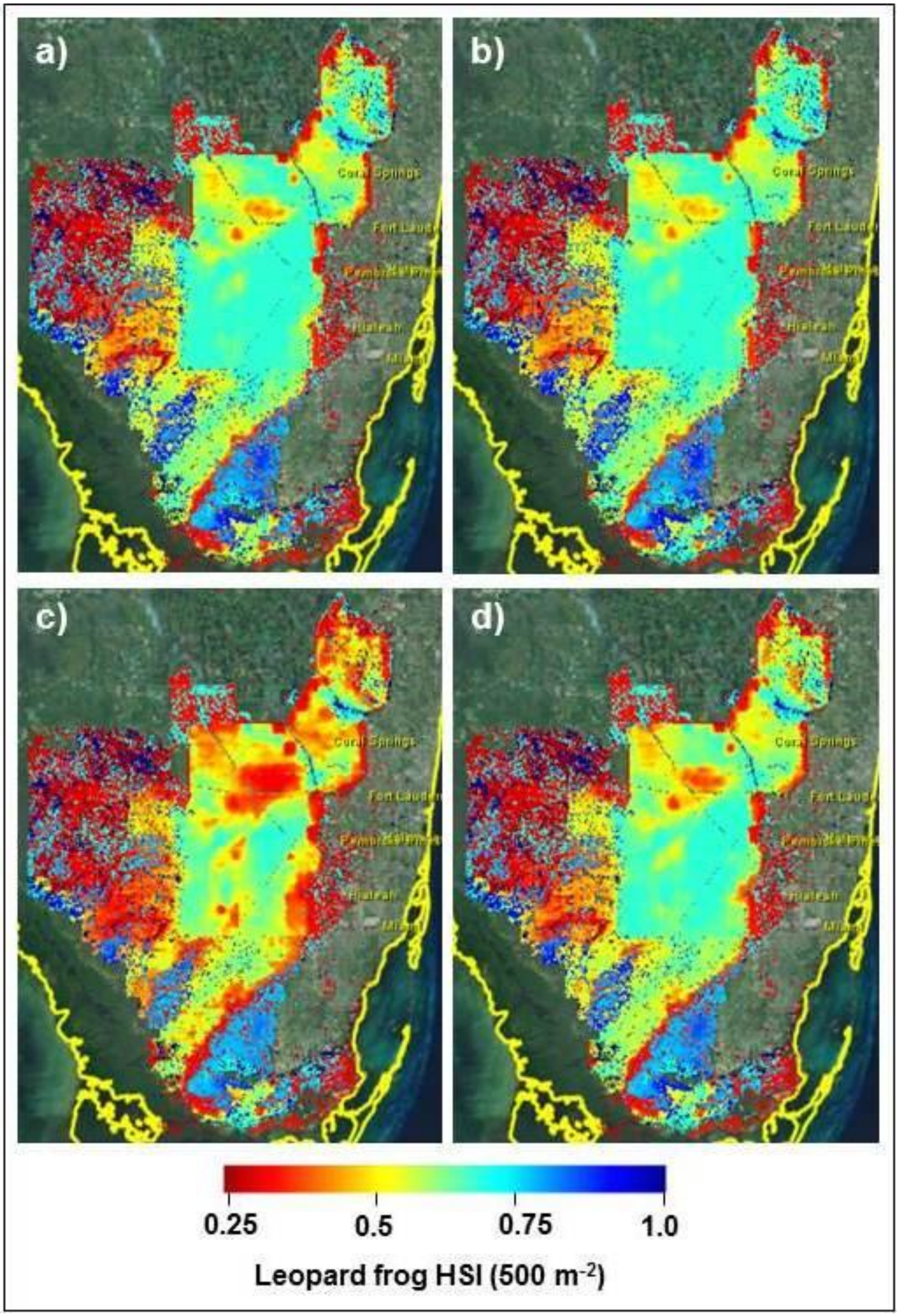
Online Resource 6. Predicted mean White Ibis habitat suitability maps (1967-2005) for 4 climate scenarios (clockwise: BASE, +RF+ET, -RF+ET, +ET). Dark green represents the highest frequency of use, whereas dark blue represents the lowest. The area of high-quality habitat is reduced with decreasing modeled rainfall, with the largest loss occurring in the -RF+ET scenario. See text for discussion



Online Resource 7. Predicted mean Wood Stork habitat suitability maps (1967-2005) for 4 climate scenarios (clockwise: BASE, +RF+ET, -RF+ET, +ET). Dark green represents the highest frequency of use, whereas dark blue represents the lowest. The area of high-quality habitat is reduced with decreasing modeled rainfall, with the largest loss occurring in the -RF+ET scenario. See text for discussion



Online Resource 8. Mean number of adult apple snails predicted in each 500 m^{-2} across the Everglades landscape for 4 climate scenarios: a) BASE, b) +RF+ET, c) -RF+ET, d) +ET. Dark blue represents the lowest density, whereas red represents the highest. The area of high-quality habitat is reduced with decreasing modeled rainfall, with the largest loss occurring in the -RF+ET scenario. See text for discussion



Online Resource 9. Mean habitat suitability index (probability of occurrence) for the leopard frogs predicted in each 500 m^{-2} across the Everglades landscape for 4 climate scenarios: a) BASE, b) +RF+ET, c) -RF+ET, d) +ET. Dark blue represents the highest quality habitat, whereas red represents the lowest. The area of high-quality habitat is reduced with decreasing modeled rainfall, with the largest loss occurring in the -RF+ET scenario. See text for discussion