Chapter 4
Using "Spatial Resilience Planning" to Test Climate-Adaptive Conservation Strategies

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Abstract How can we plan more effective conservation networks in the face of climate change, urbanization pressure and financial and policy uncertainty? We have developed and present here a strategy which we call "spatial resilience planning" or SRP. The method is an extension of "alternative futures" scenario planning (Steinitz et al. 2003) and builds from the same social and technological infrastructure. It relies on stakeholder-based participatory simulation to generate a set of scenarios which encapsulate the major uncertainties and choices faced within a geographically-bounded area. It also uses formal spatial impact models to assess the consequences of scenarios to species, habitats and to people. The difference between SRP and conventional scenario planning is in the way the scenarios are organized and tested. SRP draws a clear separation between "planning actions" (which are within the domain of influence of participating stakeholders) and all other "drivers of change." It asks the question: which are the planning actions under stakeholder influence that might best accomplish stated goals in the face of significant and uncertain exogenous forces? This can be considered a form of "policy sensitivity testing." This chapter presents a first example of this approach, in the context of Florida conservation planning under climate change.

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1 Overview

Scenario-based planning and “alternative futures” impact analyses have been show to be an effective way to organize divergent views in considering a range of options for future (Schwartz 1996; Schoemaker 1995). These methods have been widely deployed in landscape and transportation planning (Baker 2004; Godet 2001; Hulse et al. 2004; Pellier and Fiorino 2004). Conservation planning, however, operates in a slightly different context – a world in which it exerts very limited control. This domain requires less of a single fixed plan and more of an adaptive strategy. How can we effectively transition from one to the other?

Our research group has begun to develop an integrated climate adaptation planning approach we call “spatial resilience planning” (SRP). SRP is designed to generate plans and strategies which are robust relative to uncertainty. While motivated by the need to plan for climate change adaptation, the approach can also accommodate multiple types of variability, including uncertainty about future political choices or human behavior. The method is an extension of “alternative futures” scenario planning (Steinitz et al. 2003) and builds from the same social and technological infrastructure. It relies on stakeholder-based participatory simulation to generate a set of scenarios which encapsulate the major uncertainties and choices faced within a geographically-bounded area. Just as in alternative futures planning, spatial impact models are used to assess the differences between plans or policies. The difference lies in the ways in which the scenarios are organized and tested. SRP draws a clear separation between “planning actions” and all others, and it uses a sensitivity testing approach to explore the relationships between plan performance and a variety of exogenous forces. By doing so, it clarifies and quantifies the likely performance of plans which control only a few things, in a world where many other things may be changing simultaneously. It goes beyond the traditional stopping point of physical planning to investigate the question of strategy in the context of geographic knowledge.

To illustrate the approach, let us consider here the issue of conservation network design for Florida under the combination of sea level rise and human land use changes. We use as the basis for this investigation the “alternative futures” generated by the broader Everglades study described in the preceding chapter by Vargas-Moreno and Flaxman (2012). Our study area is the Greater Florida Everglades, and contributing upstream areas – a 30 county region extending from Central to Southern Florida (see Fig. 4.1).

We consider here two distinctly different conservation strategies for a 30 county region in South and Central Florida over a 50 year period. The baseline conservation model emulates current practices, which focus on piecewise preservation of the land of highest current conservation value regardless of development pressure or land cost. An alternative “proactive” strategy uses forward estimates of climate change and human development patterns to conserve lands well in advance of potential need. Both strategies are simulated spatially and temporally using a range of conservation budgets, and variations in biophysical and political climates.

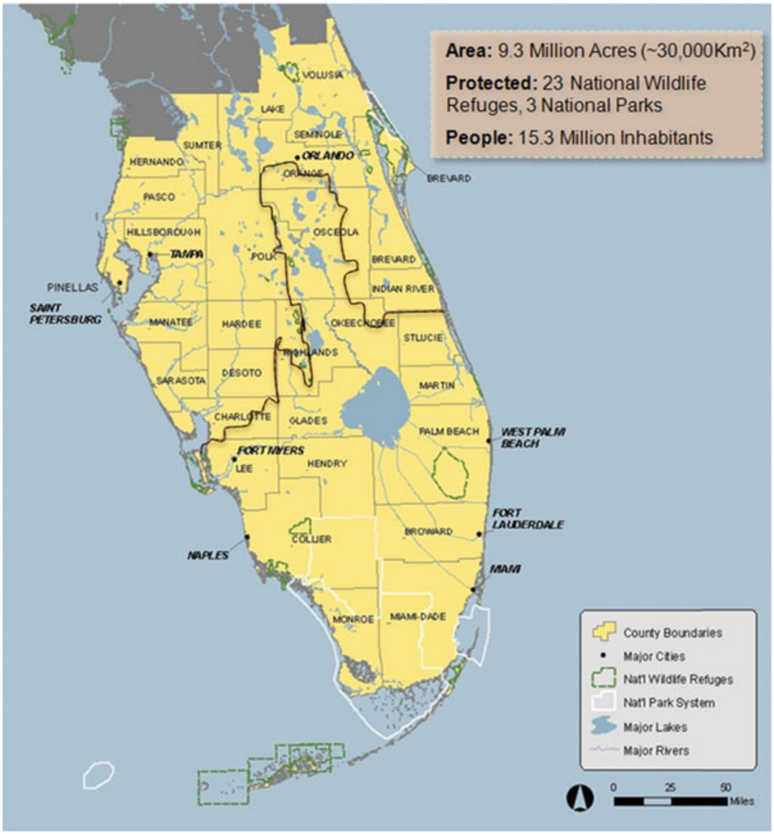


Fig. 4.1 Study area

How can we tell which strategy is more effective? The standard formulation might be to create one scenario for each strategy, then consider how each impacts various species and habitats. However, this common practice has a deep and significant flaw – it implicitly evaluates performance relative to a single model of the future. For such a comparison to be meaningful, we need highly accurate models of that single future, in this case 50 years in advance. As experienced planners and modelers, we find this notion somewhere between naïve and dangerous. Instead, we prefer to be extremely humble about our ability to project the future, and to invest significant energy in systematically exploring major points of uncertainty or policy disagreement. Only when we assess our strategy against a realistic range of conditions can we have any confidence in its likely performance.

In addition to being technically more sensible, this approach has numerous beneficial social side-effects. Because the process is anticipatory and inherently multidisciplinary, it creates an opportunity for people to think about how forces which they don’t typically control affect their area of responsibility. Essentially, it gives people time and mandate to put aside their daily work and think longer term and more strategically. Second, because it can simultaneously accommodate very different points of view, it avoids political and values fights which frequently characterize other single-future processes. There is no need to achieve artificial consensus on one view of the future – several ideas can be pursued simultaneously. Finally, the process supports adaptive planning by seriously considering a range of conditions and actions. When people have already considered major uncertainties, they are better prepared when trends or policy decisions begin to favor one particular set of contextual scenarios over others. For example, when the political and economic environment swings in a direction challenging to conservation, they can have some practical advantage from having already considered this and designed strategies likely to be as effective as possible in this circumstance.

This work was inspired by the concept of "resilience" was first elaborated by the ecologist C. S. (Buzz) Holling in 1973 and extended by himself and others in multiple papers (Hulse and Gregory 2004; Plummer and Armitage 2007; Folke et al. 2004). Holling defined resilience as a measure of how far a system could be perturbed without shifting to a different regime. His description went beyond strictly ecological systems and considered those in which human management was integral. We use the term in a related fashion but from dual vantage points. First, like Holling, we think it is unarguably important to consider natural systems as (a) dynamic and (b) systems. Conventional planning based on static map overlay can easily miss both of these points. We must begin to develop methods which work on a "shifting basemap." This point was most memorably made by someone working in a very dynamic field not usually associated with planning, hockey star Wayne Gretzky: "I skate to where the puck is going to be, not where it has been." In our opinion, too much of current conservation planning is chasing after the puck, and not enough in figuring out where we need to be. SRP assumes that the future is uncertain and dependent on the actions of others who do not necessarily share the same goals. However, by explicitly simulating possible futures, we can literally generate maps of where conservation needs to be. By testing our own strategies under realistic resource constraints, we are also able to judge how best to get there.

The second aspect of Holling's thinking – consideration of the resilience of coupled human and natural systems – remains highly challenging. The impact measures which we deploy in this study are relatively comprehensive, but individually and collectively simplistic. Our approach is able to accommodate more detailed and elaborate consideration of adaptive mechanisms, but working regionally, we are drawn to consider large-scale, essentially irreversible decisions such as whether and where development is permitted.

In an important sense, we go beyond Holling's original focus on ecological resilience, and consider resilience in a specific form of human activity not normally associated with flexibility or adaptability – the process of plan making. We find virtue in plans and planning processes themselves being resilient. Plans are critical to effective conservation, and more generally to joint long-term societal actions. But they are typically closely argued and very time consuming and difficult to modify or re-create. A plan which cannot accommodate a contextual change is either a "dead plan" (not taken seriously and therefore not functioning), or perhaps worse a "faulty plan" (continuing to operate and influence decisions even though its premises are known to be wrong).

This chapter is organized as follows. First we consider our planning context and how prior methods have attempted to deal with land use, ecology, climate change and their interactions. Then we will describe the methods we have deployed, how these play out in the specific context of Florida. Finally, we will explore which more general lessons can be taken from this example.

2 Early Twenty-First Century Planning Context and the Florida Case

The primary challenge in conservation planning is that of competing land uses. In the nineteenth and twentieth centuries, these included agricultural, forestry and industrial uses. However in the twenty-first century it is already clear that the major competing uses are related to human settlement and transportation. In particular, internet and communications technologies together with historically low automobile and air transportation costs continue a long term trend toward lower density settlement at the fringes of major urban areas. This combines in the U.S. context with two demographic trends: the retirement of the relatively-affluent and healthy post-war baby boom, and a general shift in populations from historic manufacturing centers towards the "sunbelt" and generally into coastal zones According to an analysis of census data, these trends have been relatively consistent over a 40 year period (Conway and Rork 2010). A good summary of these compounding forces can be found in a recent Pew Center report (Beach 2002). The key issues to note are that (1) coastal areas by Pew's definition constitute 17% of the nation's land area, but over half of its population, and that (2) the number of miles driven per person has consistently increased by 4x the rate of population growth over a 50-year period.

Even without considering climate change, these socioeconomic factors combine with fragmented land use and transportation systems to pose a serious conservation governance challenge. Essentially, the full value of conservation is not recognized in our economic system, either at individual or institutional levels. This is generally true for most private lands, including the many of the most ecologically-important. The only legal barriers to development are based on zoning constraints, or the documented presence of particular endangered species or wetlands. This regulatory system is for the most part fragmented, weak and easily outflanked. For example, despite an official policy of "no net loss" of wetlands, in recent years the U.S. Army Corps of Engineers has granted over 99% of wetland fill permit requests in Florida, with more than 100,000 acres of loss officially permitted (Pittman and Waite 2009). The result is a familiar catalog of ecological decline, depressingly similar whether measured in terms of species, habitats, water or other resources.

Therefore the general purpose of broad-scaled conservation planning is to help develop strategies which can inform both public and private voluntary conservation activities. On the public sector side, these should tie into existing fee-simple conservation acquisition, comprehensive planning, endangered species habitat planning and wetlands planning efforts. On the public-private partnership side, these should help guide individual and voluntary land stewardship activities, including land management practices and conservation easements. In both cases, it is of great benefit to operate well-ahead of market pressures and to attempt to link conservation activities into a strategy which considers comprehensively which activities occur when, where, and by whom. These have different time windows depending on investor risk tolerance, but are generally less than 5 years for private developers, and somewhat longer for agriculturalists and ranchers with major land assets (Chicoine 1981; Goldberg 1974).

3 Drivers of Change

Recent work in conservation planning has concentrated on how shifting habitats and species populations may affect biodiversity conservation (Burkett and Kusler 2000; Feagin et al. 2005; LaFever et al. 2007; Parmesan 2006). This is clearly important, but unfortunately addresses at best only half of the challenge. It is equally important to recognize that ecological stressors are now themselves being altered by climate change. First, there is every reason to believe that human populations will adapt and shift in response to climate change (Stephenson et al. 2010; Moser 2005; Plummer and Armitage 2007). Those responses potentially affect not only settlement patterns, but also many other sectors and land uses impacting conservation, for instance including fisheries, agriculture and forestry. Second, as supplies of natural resources such as water become less reliable, ecological systems will likely face additional competition from human consumptive uses (Burkett and Kusler 2000; Diamond 2005). Third – and more positively – human choices and policies for climate change mitigation provide an opportunity to alter economic, transportation and land use decisions in ways which might much better support conservation (Sheppard et al. 2011).

The influences of urbanization, climate change and land use planning constraints are all individually well-studied within conservation planning, yet interactions between these driving forces are rarely considered. This situation has led to repeated calls over at least a decade for integrated analyses, as well as a recent review which concludes “studies that include only one or the other driver are likely to inadequately assess impacts (de Chazal and Rounsevell 2009).”

One possible approach is to attempt to “downscale” global climate scenarios not only in terms of their impacts on regional climate, but also in their assumptions about regional socioeconomic trajectories. Solecki and Oliveri simulated how climate change might impact urban growth in terms of assumed influence on land use demand (Solecki and Oliveri 2004). However, the great difficulty with this approach is that there are myriad regional and state-level scenarios which are consonant with a global scenario, and a direct interpolation of global trends across all spatial scales can be counter-factual. National population shifts are driven by forces not considered in global estimates. Therefore, while it might make sense to craft U.S. national scenarios to be nested within global ones in terms of total population, it makes little sense to think about Florida's future population as a simple proportional downscaling of U.S. population. Florida's percentage share of the U.S. domestic population has not remained constant for the last 50 years, and there is no plausible reason to believe it will do so for the next decades (Flynn et al. 1985; Conway and Rork 2010). Conventional demographic analyses developed by University of Florida researchers are available. These estimates have been conducted over a 40 year period and are typically accurate to within better than 2% per decade, with more recent estimates being even more accurate (Banko 2011). The bigger issue this points out is methodological: how can "top down" scenario planning methods be melded with "bottom up" regional scenarios? In the specific case mentioned, the overall population equation balances because of domestic and international migration. However, this is not necessarily the case.

The question of likely human adaptation measures is clearly an important one. However, the literature in this regard remains surprisingly limited. An outline of the major challenges was developed by Tol and colleagues in 1998: "Most of the studies of climate change impacts tend to make simple assumptions about adaptation. They either ignore adaptation completely, or assume arbitrary measures or complete changes in behavior, infrastructure, and institutions without examining the costs and feasibility of changes." (Tol et al. 1998). There is no shortage of vulnerability assessments, but these fall short of projecting likely responses, in large part because they ignore behavioral issues, costs, or both. Since there are few appropriate example cases to draw from, we are left to reason by analogy to other types of risk/response, or to consider qualitative typologies of recommended actions. The most recent and relevant study of climate change risks in Florida was produced by Tufts University (Stanton et al. 2007). Among its major findings are that sea level rise and storm surge in particular could threaten billions of dollars in coastal development and associated infrastructure. What people choose to do will likely have much to do with not only how much climate change occurs, but also who pays for what, and which rules govern.

4 Conservation Consequences of Changes

In terms of ecological responses, the challenge of climate change planning for conservation was well characterized by Opdam and Wascher (2004). They developed a conceptual model which makes the point that key interactions occur at two scales. At biogeographic scales, climatic factors are well known to limit species ranges, either directly through biological sensitivities or indirectly through impacts on habitat and intraspecific competitive advantage. Meanwhile, at landscape scales, species metapopulation theory indicates that the availability and organization of habitat can influence species viability. In a habitat-constrained, climate-changing world, these two scales interact. As Opdam and Wascher put it "the response chain from climate change to distribution pattern is mediated by landscape cohesion. (idib)"

Using very different techniques, Iverson and Prasad (1998) came to similar recommendations. They used regression tree modeling techniques to predict future vegetation ranges under various climate change scenarios, concluding that "given these potential future distributions, actual species redistributions will be controlled by migration rates possible through fragmented landscapes." Finally, recent work in a very different region re-affirms the potential importance of climate-land use interactions at landscape scales. Working in the Andes, (Feeley and Silman 2010) predicted the distributional responses of hundreds of plant species to changes in temperature incorporating population density distributions, migration rates, and patterns of human landuse. In this landscape, they found an "overriding influence of land-use on the predicted responses of Andean species to climate change."

At a very detailed level, there are numerous studies which consider how individual adaptation or mitigation mechanisms might impact biodiversity. Of particular relevance to Florida are studies which investigate the impacts of existing mechanisms for coastal "armoring." This is a potentially likely response in certain parts of Florida, although its utility is severely limited in many cases by very pervious limestone geology. (In such areas, measures such as installing rip-wrap can be somewhat effective in mitigating storm surge, but not base tidal inundation.) An example of the known effects, based on a paired "natural experiments" method, show significant effects on shorebirds (2x less species richness and 3x less abundance on armored segments) (Dugan et al. 2008). Birds which use beaches primarily for roosting showed even strong effects (ranging from 4x to 7x reductions on armored segments) (ibid.). Clearly, there is room for concern that single-purpose adaptation mechanisms designed to protect property could have significant inadvertent impacts on wildlife. While specific results are likely to vary highly dependent on local context, the combination of climate change and land use change are pervasive enough to merit the development of a consistent set of methods.

5 Strategy of Selected Simulation Approach

A detailed elaboration of the AttCon simulation modeling process and its application to Florida can be found elsewhere (Flaxman and Li 2009; Vargas-Moreno 2011). In basic terms, we chose to deploy a rule-based deterministic land use allocation model. The choice was motivated by two primary factors. The first was that the research team felt that future land use changes in the region would vary significantly from historic trends based on scenario constraints. Therefore, statistically-based models would not be appropriate, since we wanted to be able to investigate the relationship between rules and responses. The second was that the model had pedagogical as well as predictive purpose, and needed to be run at least 24 times across a very large region. This argued for use of a deterministic model which accepted exogenous predictions of population growth, rather than a microsimulation approach.

In the AttCon modeling formulation, potential development units are allocated based on an estimate of relative suitability for a specific purpose, and conflicts are resolved using an explicit prioritization scheme which defaults to economic willingness to pay under "business as usual" scenarios. Under proactive scenarios, public purposes are allowed first right of refusal within the allocation scheme, under the assumption that government can choose to intervene. This allows a single consistent method for allocation of conservation lands, given a prioritization and an acquisition budget.

The major refinement required relative to prior implementations was an integrated submodel simulating sea level rise and human response to it. This task is somewhat simpler in Florida than in other areas because most coastal areas are very flat and composed of pervious limestone geology. This means that adaptation options are relatively limited, since sea walls and dikes are infeasible. This made it feasible to use a simple "bathtub" model of mean high tide sea level to estimate tidal inundation based on projected SLR. It should be noted that two important sources of risk and their relation to climate change were not accounted for due to modeling limitations. We were unable to consider storm surge, since this requires dynamic modeling considering near off-shore bathymetry. We also could not consider changes to hurricane frequency or intensity, since data linking these phenomena to climate change are not spatially available for the region. Both of these factors would likely compound the effects which we are able to estimate using simple SLR modeling.

The SLR model provided the basic environmental hazard information needed to project human response. Our AttCon model is able to track and project the major physical structure and socioeconomic characteristics which would likely be relevant. Because the model simulates the allocation of different real estate submarkets, it understands both the income characteristics of a given location and the age and type of built structures. We might expect to find different responses based on median income and physical structure characteristics. However, because actual empirical response data are not available, we were faced with the dilemma identified in our literature review – how to account for varied but realistic responses to coastal inundation. Dozens to hundreds of potential adaptation responses have been suggested in the literature and each of these individually and collectively could have wildlife impacts. Because of the wide variety of potential mechanisms and lack of literature on preferred responses given issues of cost, practicality and institutional barriers, we chose abstract the options.

In spatial terms, there are basically four coastal climate adaptation strategies available. The first is "adapt in place." This means that the basic form of activity remains in the same location, with whichever adjustments are needed to buildings, conservation, infrastructure or current land use practices. The second is "shift locally." This means that the same activity continues in the nearest available location, which strong preference to those areas under the same management authority as the original location. The third is to "move regionally." An existing use continues to persist, but is forced to relocate within the same region. The forth is to "quit or move long distance." In this case, a function either disappears entirely, or moves entirely away from the region in question.

The first-order task in considering human land use responses to climate change is to consider likely responses relative to this spectrum of basic adaptation types. For a given biophysical or socioeconomic condition, this could be a single response, or a probability distribution. For example, consider coastal condominium buildings under historic to current levels of coastal hazard, sea level rise and storm surge. Something close to 100% of this land use type adapts in place, typically rebuilding unless legally prohibited. Under a sea level rise scenario in which the same use is inundated at every high tide and insurance rates rise dramatically or insurance is no longer available, the response curve is likely to shift considerably.

Pending further empirical research into the likely values for such basic adaptation types, we chose to implement a simplified decision rule which is described below. For now, we simply note the dilemma faced in such a circumstance: there are many cases in simulating alternative futures where human attitudes towards future events and circumstances are important but unknown. The scenario formulation does not avoid this, but does allow us to press forward with clearly stated assumptions. Using spatial resilience planning methods, we can also test the relative importance of these assumptions, and direct future research toward their clarification. For example, we could survey appropriate groups about their likely response within scenario conditions.

Such changes are in detail unpredictable, and subject to significant uncertainties. This has led some to adopt a "wait and see" position, attempting to defer such analyses until more definitive science is available. However, we believe that this is a fundamental strategic mistake. Conservation planning is a social learning process, not simply a matter of technical analysis. New issues and information must be deliberated within a number of public and private decision-making processes before actions can be initiated. The key challenge of conservation planning under climate change is not to come up with single decision based on new information or analysis. The challenge is to develop planning methods and decision-making structures which are able to routinely incorporate uncertainty, changes in science and conflicting human values. While climate science is improving rapidly, human adaptation and political decision-making is integral and will remain inherently unpredictable. Therefore, we must develop and test planning methods now which are capable of routinely incorporating new information and which are robust in the face of both scientific and political uncertainty.

6 Methods

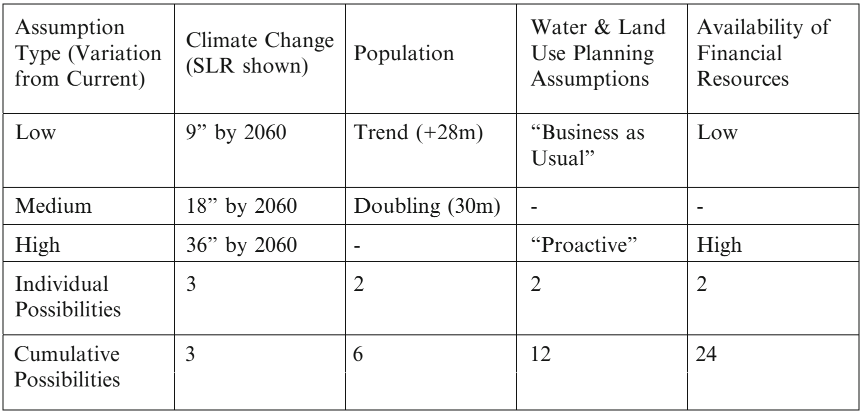
Spatial Resilience Planning or SRP can be considered a technique for using scenarios to generate and refine plans. Two basic steps are required. The first is to separate "exogenous" and "endogenous" scenario variables. Exogenous variables are used to develop "contextual" scenarios, and the endogenous factors to develop "designs" or "plans." In the context of stakeholder-based planning, exogenous variables are those which the group does not have substantial power to change or influence. In most locations, these include global climate change, national and international economics, and population in- and out-migration. Endogenous variables are the opposite: these include aspects of management discretion and policy in which there is significant choice. In our case study area, these decisions included how to manage current conservation areas, which additional lands to conserve, and which types of conservation actions to deploy. These decisions are not unconstrained: managers have limited legal discretion, jurisdiction and budgets. But within these constraints, very real decisions must be made.

The second step of SRP is to explicitly "stress test" plans against exogenous contexts. This can be done for plans as a whole, or for specific plan elements or parameters. In this case, we bundled a set of conservation strategies into a group we term "proactive," but varied the level of financial resources provided. Because both aggregate scenarios and their component elements do not have explicit probabilities assigned to them, we are limited in the degree to which we can quantify resilience. Here we deploy a basic, but effective mechanism: we spatially identify the frequency and nature of conflicts between an endogenous scenario element and the full scenario set.

In our specific case, we summarize the area in which conservation is possible given exogenous constraints. At an aggregate level, such "conflict analyses" are an indicator of plan performance. By this measure, a resilient plan is one which is relatively robust in the face of a wide range of scenarios, but still accomplishes its objectives. This dimension of plan performance is complementary to more traditional ecological performance metrics, which can also be computed from the same input data. Therefore, an "effective" plan may be one which scores highly according to multiple ecological or social criteria and is resilient. Finally, an important aspect of spatial planning is that our conflict analysis and resilience measures are themselves spatially variant. They can therefore indicate which areas or regions are relatively more or less impacted, and where strategies are effective or not. This provides important opportunities to geographically tailor policies so as to improve plan performance across different socioeconomic and environmental conditions. In this example, we only look at a single round of conservation strategy design. But the results from conflict mapping could be used in detail to look for other areas which met the same goals, in a process of iterative refinement.

7 Contextual Scenarios

Our contextual scenarios were scoped and developed using an in-depth participatory spatial simulation modeling approach. For our purposes here we only outline the major driving variables considered in the process – a detailed description of the scenarios and modeling process is provided in the previous chapter (Vargas-Moreno 2011). Participants in this process created a set of scenarios which recognized four top-level dimensions: climate change, human population demographics



Assumption Type (Variation from Current)	Climate Change (SLR shown)	Population	Water & Land Use Planning Assumptions	Availability of Financial Resources
Low	9” by 2060	Trend (+28m)	“Business as Usual”	Low
Medium	18” by 2060	Doubling (30m)	-	-
High	36” by 2060	-	“Proactive”	High
Individual Possibilities	3	2	2	2
Cumulative Possibilities	3	6	12	24

Fig. 4.2 Contextual scenario parameter matrix

and preferences, availability of financial resources, and land and water policies. For each dimension, stakeholders developed a bounded set of parameter values or assumptions. For example, qualitative descriptions of climate change included low, medium and high groupings, each quantitatively defined in terms of sea level rise, temperature, and precipitation based on IPCC 2007 model outputs (IPCC 2007). The land, water and conservation rules dimension was the most complex, with over 100 separate policies considered and packaged into two major grouping: “business as usual” (B.A.U) and “proactive.”

The “alternative futures” portion of the study developed and discussed five priority scenarios, which reflected managers’ priorities for the most important multidimensional combinations. In order to limit the potential propagation of scenarios, stakeholders were encouraged to strictly limit the number of dimensions and choices along each dimension. Based on the stakeholder’s allocation of these resources, this had the consequence of reducing consideration of moderate water and land use planning assumptions and financial resources. Also note that stakeholders chose to include one climate change scenario that was higher than IPCC standard 2007 scenarios and reflected the possibility of non-linear melting of the Greenland ice sheets.

In order to conduct the sensitivity testing required by this approach, we simulated every logical combination of the major driving variables, leading to a total of 24 scenarios. This set incorporated three levels of climate change, two levels of human population change, two sets of land and water management policies, and two levels of public finance. While significant additional setup and computing time was required, we were able to use the same AttCon simulation model (Fig. 4.2) (Flaxman and Li 2009).

8 Simulation Modeling Using AttCon

After initial scenario assumptions and parameters were validated with stakeholders, we constructed a spatial simulation model projecting future changes in land use for the region. In this case, we simulated seven land use types: high, middle and low-end urban residential housing, rural residential development, agriculture, ranching and conservation.

We also included a simulation of sea level rise (SLR). We used a simple “bathtub” model based on projected sea level in 2020, 2040 and 2060, terrain elevation and contiguity with the ocean. All areas under mean sea level and contiguous with ocean were considered permanently inundated. Our overall terrain surface was obtained from USGS’s National Elevation Dataset. We refined this terrain by overlaying LIDAR-based bald earth terrain elevation data from NOAA and from the Everglades Depth Estimation Network (EDEN) where available.

Since we were unable to find scientific literature providing more appropriate guidance on human responses to sea level rise,, we simulated two logical possibilities. In our “business as usual” scenarios, we allowed building wherever economic pressure and zoning allowed it. Where developed land was inundated, we assumed that a certain percentage of previous residents would stay within our study area, and the rest would leave it. Those who stayed would exhibit the same land use preferences as prior to inundation, and would essentially be displaced within the region. In our “proactive” scenarios, we implemented a form of zoning which blocked any new development from areas subject to future sea level rise. Where current residents were displaced by SLR, we made the same assumptions about redistribution as in the other scenarios – for example that 85% would stay and 15% would leave.

The outputs of the model are projected land uses (and inundation) over time, in the form of raster GIS grids. Typical model outputs are shown in Fig. 4.6.

9 Conservation Design and Plan Simulation

There have been multiple generations of plans for the conservation of the Greater Florida Everglades, and for Florida as a whole. Our interest is this study was not to replicate such efforts, but instead to consider how resilient they may be to climate change, urbanization and other pressures. To estimate conservation attractiveness under current plans, we blended two proposals: the Critical Lands and Waters Identification Project (CLIP)(Oetting and Hoctor 2007) and the Florida Ecological Greenways Network (Hoctor and Center 2004). CLIP was developed by researchers at the University of Florida and the Florida Natural Areas Inventory for the Florida Fish and Wildlife Commission (Oetting and Hoctor 2007). The Greenways network was developed by the University of Florida GeoPlan Center and Florida Dept. of Environmental Protection (DEP), Office of Greenways & Trails (Hoctor 2001).

Both existing plans have been published electronically in GIS form by their respective authors, greatly facilitating this kind of analysis. However, both plans exceeded likely short-run conservation resources by a very wide margin. We therefore found it necessary to develop temporal "phasing" in order to make the plans and their relative priorities explicit in our simulations. For this reason, the resulting analyses reflect our estimation of the likely implementation of these plans, based on the priorities expressed within them.

In our composite conservation attractiveness model, we used CLIP priorities as our top priority areas, passing through their rankings directly. Therefore, our top priority areas are identical in location and extent to CLIP's. We then underlayed the Florida Greenways priorities, ranking them as "next most" attractive while maintaining their relative internal ranking order. All analyses were conducted using 50 m × 50 m (1/4 ha) grid cells. In our conservation allocations, we used distance to existing conservation as a "tie-breaker" between identically-ranked grid cells.

9.1 Conservation Strategies

Our key "endogenous" variable was conservation strategy. This took one of two forms. Under "business as usual" scenarios, we attempted to replicate current conservation practice. Based on review of the Florida Forever program and CLIP prioritization, we used a so-called "greedy" algorithm. This took each potential conservation acquisition in rank priority order, based on availability of land and funds. We did not attempt to replicate a portfolio-based method, because that did not reflect what we had observed occurring in practice.

In the "proactive" conservation scenarios, we simulated a rather different strategy, but for fairness in comparison using the same greedy algorithm. We used the contextual scenarios to grant the proactive method full forehand knowledge of future land use, and allowed it to re-prioritorize acquisitions based on this knowledge. In particular, the proactive scenario placed as its highest priority lands which would otherwise become urbanized, and lands which formed potential "climate corridors" connecting habitat likely to be inundated under SLR to the nearest large protected natural areas.

9.2 Conservation "Demand"

Conservation "demand" estimates varied by scenario based on both policy and financial resources availability. We began by considering this history of land conservation over the last 50 years. For the most recent decade, we used a full parcel-scale GIS database of acquisitions provided to us by the Florida Natural Areas Inventory (Oetting J 2010, Personal communication). This was "clipped" spatially to our study area to provide a relatively exact measure with purchase prices, acreages and acquisition

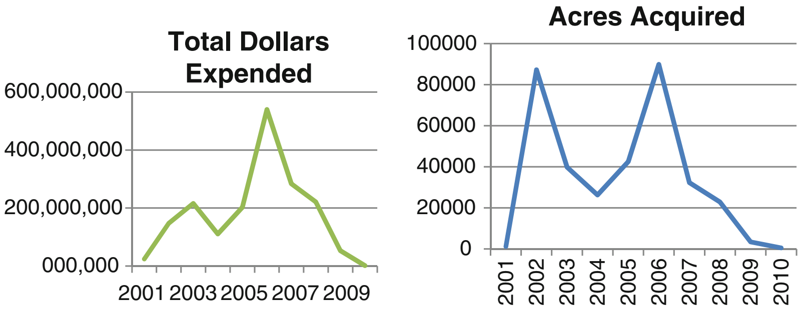


Fig. 4.3 Historic conservation land acquisition in South Central Florida

dates. For the period from the 1960s to the 1990s, we were only able to obtain program-level aggregations of total acreages and costs over a project lifetime (Oetting J 2010, Personal communication). We pooled all of this data, estimating annual acquisitions for project-level data using simple averages.

For "business as usual" scenarios under typical resource availability, we extrapolated mean historic conservation acquisition rates over the last 50 years forward 50 years. For proactive conservation demand, we used multipliers of historic rates based on financial resource availability. These estimates do not include other conservation activities such as fully-private conservation efforts. However, fully private conservation in the last decade in Florida has accounted for only approximately 10% of total acreage (Oetting 2010, Personal communication). Our dataset did include all public-private partnerships and Federally-funded acquisitions such as those undertaken as part of the Comprehensive Everglades Restoration Project (CERP).

The main current conservation lands program within the state is known as "Florida Forever." While originally budgeted at $300 million per year, this program has recently been underfunded because of the Florida state budget crisis. Over the last decade, however, the program achieved just under two-thirds of its original intended scope. Relative to other state acquisition programs, this accounted for a still-impressive $1.8 billion dollars in conservation lands acquisition; purchasing 621,000 acres.

Predicting future conservation budgets is obviously very difficult, and subject to substantial uncertainty. Annual plots show considerable variation over the last decade, with a very negative recent trend. However, this is also an advantage of a scenario-based approach, since we can simultaneously consider multiple possibilities (Fig. 4.3).

Note that our formulation of conservation "demand" embeds the notion of societal "willingness to pay" based on empirical estimates. This varies from ecological optimization-based concepts such as "irreplaceability" and "functional redundancy" (Margules and Pressey 2000). This is a measure of likely available conservation resources scaled to a particular place, not a conservation goal. The difference is very dramatic in the case of Florida. The total land area included in the CLIP and Florida Greeways prioritizations covers more than 50% of the total land area of the state, and the current total fraction of conservation land across the state is 28%. This difference represents millions of acres and billions of dollars. Therefore, our conservation simulation results are sensitive to which decisions are made “within” the overall prioritization schemes in actual active use, as well as to variations in overall conservation budget. For example, our current conservation simulations reflect actual practice in which the prioritization schemes used are biologically-driven and do not explicitly consider land cost. In recent conservation efforts, the average land cost was just under $3,000 per acre. However, the most expensive parcels acquired were approximately $2,000,000 per acre (occurring mostly in the Florida Keys).

10 Results

10.1 Overall Urban Pattern

Our contextual simulations projected a wide range of urban land use drivers over the next 50 years, depending on the population estimates, level of financial resources and land use policies in effect. What kind of variations did this cause? The simplest aggregate measure is development frequency. In raw form, this is simply the count of scenarios in which a particular location was urbanized, ranging in this case from 0 to 24. This can obviously be normalized to a percentage score, but for simplicity in representation, we chose to reclassify it into three categories: land not urbanized under any scenario, land urbanized in less than 50% of the scenarios, and land urbanized in more than 50% of the scenarios. This classification can be seen in Figs. 4.4 and 4.5.

In general, allocations remained relatively faithful to existing spatial patterns, which is a reflection both of the conservative nature of the rules used to generate them and the lack of new geographic limits, transportation corridors, or ownership constraints. For example, all scenarios showed continued population growth along both coasts. However, the major change evident relative to historic trend is the vast amount of development in the Northwest and Northcentral portions of our study area (Fig. 4.6).

10.2 Conservation Amount and Pattern

Our most striking finding is that sea level rise under most scenarios may inundate much more land than is being added to the conservation network. For example, under our high climate change scenario (1 m SLR by 2060) with “business as usual” conservation, 0.28 million acres of conservation are acquired. However, under the same scenario, 1.25 million acres of conservation land are lost to sea level rise. The effects of sea level rise vary across the region, but are particularly pronounced in the Florida Keys, and in the Southwestern corner of the state (see Fig. 4.6).

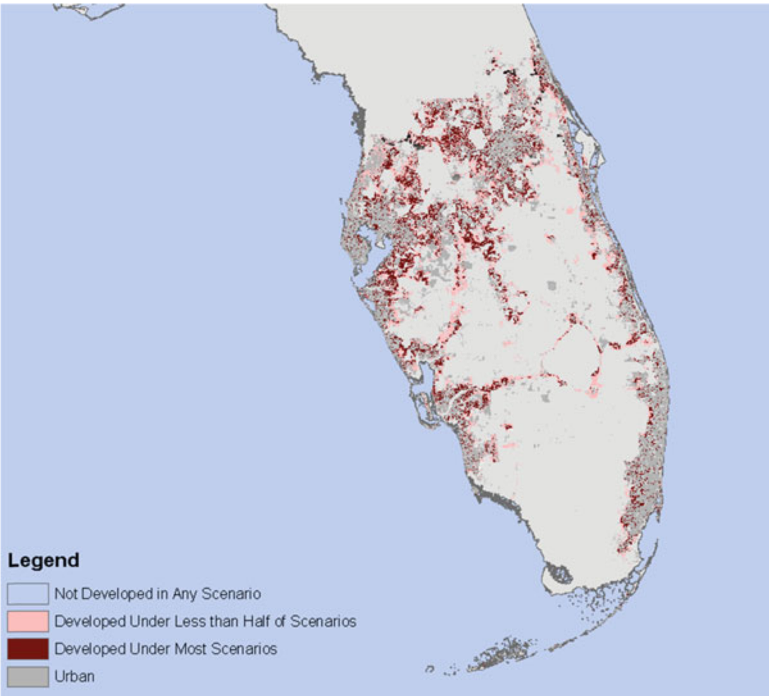


Fig. 4.4 Urbanization pressure across 24 scenarios

Development	Cells	Hectares	Acres	% Total
None (0 scenarios)	26,598,366	6,649,592	16,889,962	85%
Moderate (1-12 scenarios)	2,470,182	617,546	1,568,566	8%
High (12-24 scenarios)	2,161,654	540,414	1,372,650	7%
Total	31,230,202	7,807,551	19,831,178	100%

Fig. 4.5 Development pressure across multiple scenarios

It is perhaps not surprising that coastal wildlife refuges are at risk from SLR. However, the proportions of land lost are striking. In all but the lowest SLR scenarios, upwards of 50% of the existing coastal national wildlife refuges will be inundated (Fig. 4.7).

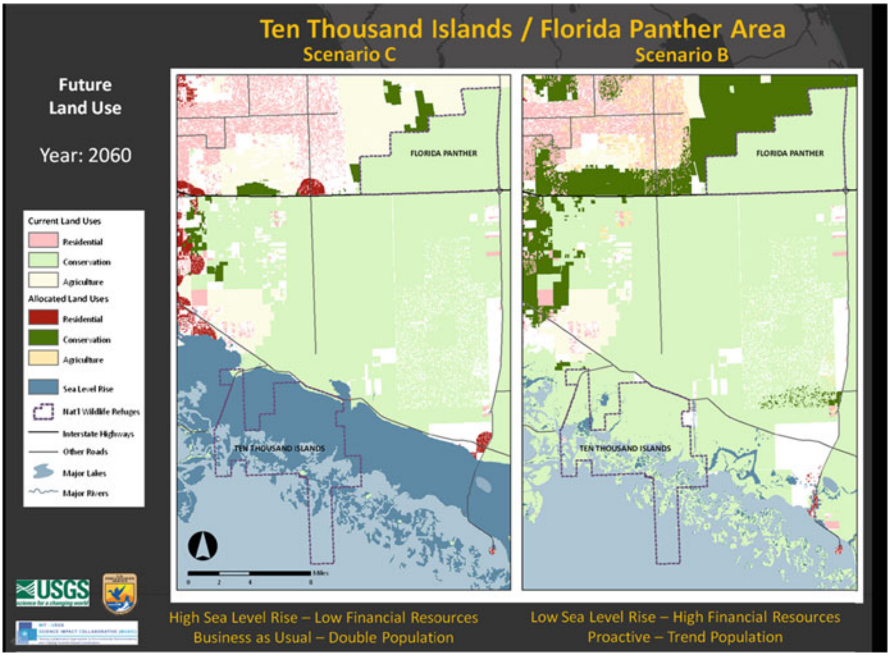
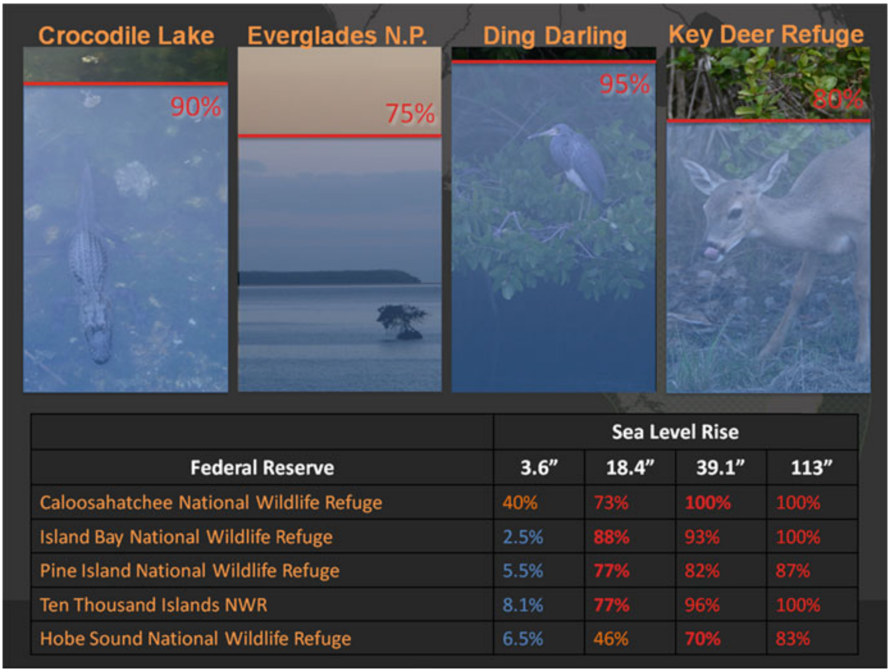


Fig. 4.6 Detail of projected sea level rise, land use and conservation change



	Sea Level Rise			
Federal Reserve	3.6″	18.4″	39.1″	113″
Caloosahatchee National Wildlife Refuge	40%	73%	100%	100%
Island Bay National Wildlife Refuge	2.5%	88%	93%	100%
Pine Island National Wildlife Refuge	5.5%	77%	82%	87%
Ten Thousand Islands NWR	8.1%	77%	96%	100%
Hobe Sound National Wildlife Refuge	6.5%	46%	70%	83%

Fig. 4.7 Percentage of key conservation areas potentially inundated by sea level rise

11 Conservation Resilience to Urbanization

The second component of conservation plan resilience is performance relative to urbanization. To assess this, we extracted urban developed areas from each scenario and spatially intersected them with conservation plans to form "conflict maps." To further characterize the conservation significance of such conflicts, we also overlaid predicted future urban growth on various environmental resource maps. For our sampling universe, we limited our consideration to those areas within the study region which have been identified under current conservation planning as priority areas, and which are not currently protected. These represent the opportunity areas for future conservation. Thus the measures of impact presented here are measures of future performance of current plans under varying exogenous conditions.

We considered several individual species as well as a broader habitat-based measure (endangered natural communities). The species considered were picked in consultation with our stakeholders to represent a range of life history characteristics and habitat requirements. The species were constrained to those for which recent published digital estimates of actual habitat we available. We utilized the most recently available revisions of the Florida State Wildlife Commission's "Potential Habitat by Species" (2009) since these had been peer reviewed and were based on a recent depiction of underlying land cover consonant with our other data. In order to represent broader-scale natural habitat types, we used two datasets from the Florida Natural Areas Inventory: "Under-Represented Natural Communities" and "Fragile Coastal Resources" (Oetting J 2010, Personal communication). In order to provide a synoptic index, all subcategories of these data sets were reclassified into a single mask, which we collectively term "Rare or Fragile Natural Communities."

In order to compactly illustrate and discuss these results, we turn again to two of the more extreme scenarios. In Scenario C, we have the highest rates of population growth and sea level rise, "business as usual" public policies and limited public financial resources. Under these conditions, urbanization would impact several hundred thousand acres of habitat. For the Scrub Jay and for rare natural communities, direct impacts from urbanization would convert almost one fifth of remaining habitat. For the Florida Panther and Caracara, potential conflicts are lower in percentage terms, but still represent tens of thousands of acres.

Under Scenario B, we have some of the best likely future conditions for conservation. Climate change and consequent sea level rise are low. Population growth is similar, but because of extensive redevelopment of transit-oriented development nodes identified by the counties, the total amount of green field development is reduced. At the same time, "proactive" land conservation policies are adopted and are supported with significant levels of public funding. In these circumstances, habitat losses due to urbanization are relatively minor, in no case exceeding 4%. This still amounts to a total of over 50,000 acres of habitat conversion in aggregate, so there is room for improvement. A drill-down analyses of these data could specify exactly which natural communities or which patches of habitat are at risk and roughly when, allowing experts in those species or areas to undertake more detailed planning (Fig. 4.8).

Conservation Element	Potential Conservation	Conflict with Scenario B		Conflict with Scenario C	
		Acres	%	Acres	%
	Area (ac)				
Black Bear	2,976,602	25,576	0.9%	385,503	13.0%
Florida Panther	1,021,181	10,080	1.0%	95,106	9.3%
Scrub Jay	108,493	3,980	3.7%	20,201	18.6%
Caracara	2,009,025	9,142	0.5%	105,060	5.2%
Rare or Fragile Natural Communities	616,794	14,495	2.4%	114,766	18.6%
Proposed Florida Greenways Corridors	1,676,713	78	0.0%	57,451	3.4%

Fig. 4.8 Conservation/urban conflict analysis

12 Overall Conservation Conflict Mapping and Plan Resilience to Urbanization

Using the development frequency classes described above, we can ask the conservation conflict question in from a land-based perspective. Of the total study region, what percentage and absolute amount of land is under highest development pressure considering all scenarios? Overall less than 7% of the total study area is at highest risk of development, amounting to roughly 540,000 ha or 1.4 million acres. A very similar fraction (8%) is at moderate risk of development (620,000 ha or 1.6 million acres were urbanized in half or less of the scenarios).

How well did the two conservation strategies perform overall relative to this range of urban pressure? To answer this question, we must consider the alternative "fates" of grid cells urbanized under one or more scenarios. For example, we can compare the "business as usual" and "proactive conservation" strategies under the assumption of high public financial "resources across" the range of climate change scenarios. In order to focus this further, we can narrow our consideration to only those lands of relatively high biodiversity conservation values. By definition, both conservation strategies were given the same budget. Which strategy worked better? There are a myriad of ways of characterizing the "better" portion of the question, since this could be asked from the point of view of any species, or habitat. It turns out that perhaps the most useful aggregate measure to look at is the difference between the high-value conservation areas which would otherwise have been urbanized.

To compute this measure, we extract those cells which were conserved under "proactive high" but which would otherwise have been urbanized (despite normal conservation practices). This area represents roughly 15,000 acres (6,000 ha) if you consider only the portions of the land of highest conservation value. Since much of these areas are on ranch and forestlands with large lots, these figures can vary considerably if the purchase of the full surrounding parcel is considered. For all such

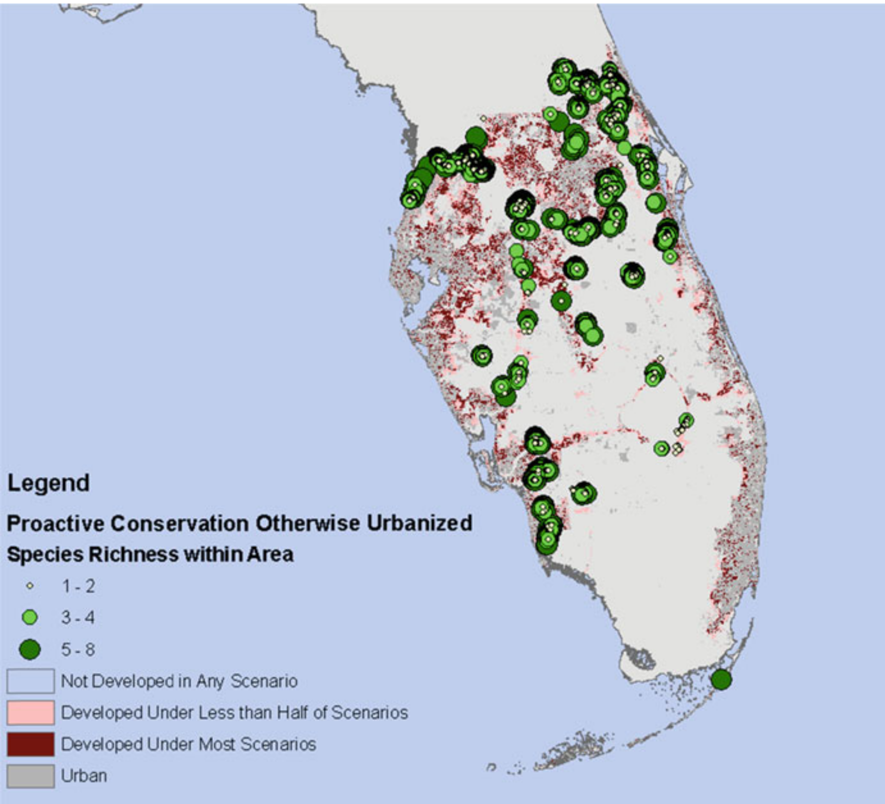


Fig. 4.9 Areas conserved under 'Proactive' strategy but developed under 'Business as Usual' (*dots* represent the predicted habitat for Florida state-listed species)

areas, the area required increases to just over 208,000 acres (82,000 ha). If only the priority portions of parcels could be purchased, their 2009 fair market value would be 65 million dollars. However, if the full parcels would require purchase, the price tag would increase to 882 million dollars. In reality, a figure between these two is most likely, especially for larger parcels.

Where are these lands? Well, they range from the Florida Keys up to the Northern boundary of the study region, but are primarily located at the fringes of existing rural residential development in the North and Northcentral portions of the study area. They form a proportionally very small, but very critical portion of Florida's conservation future. Essentially, these are the areas which current conservation strategy misses, and which can be projected with relatively high confidence to otherwise be urbanized. With the exception of the Keys and some sites around Charlotte Harbor, most of these sites are not directly subject to sea level rise (Fig. 4.9).

A more detailed zoom into the same data provides an example of how such information might be used. For example, consider the areas outlined in white in

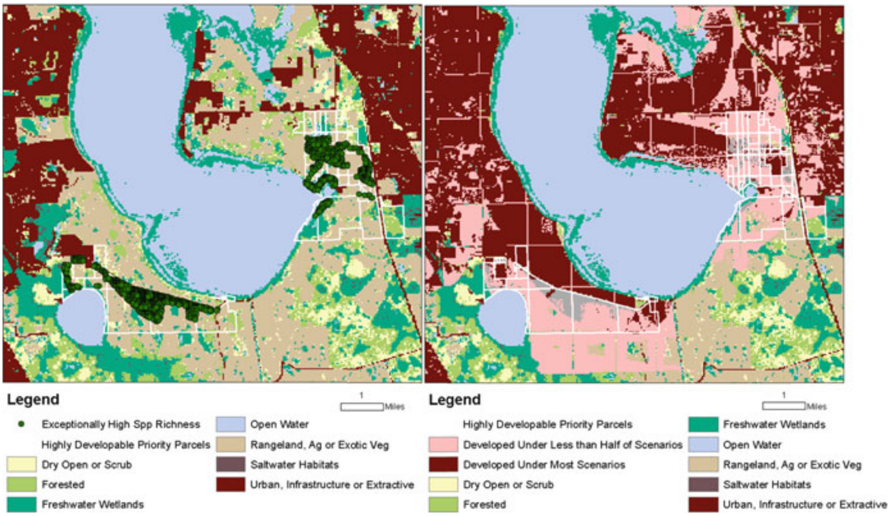


Fig. 4.10 Example of exceptionally high conservation value areas predicted to be developed under current conservation practices, but protected under "proactive" strategies

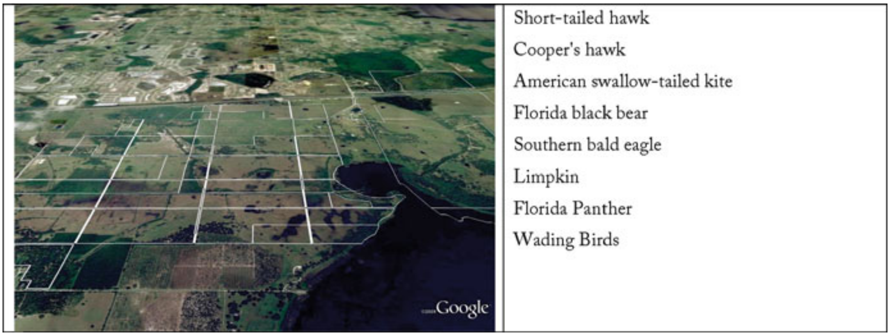


Fig. 4.11 Perspective view of parcels and predicted state-listed species habitat (Note open water, wetlands to uplands gradient and adjacent development)

Fig. 4.8. These represent 33 parcels with some of the highest species richness in the state. In particular, they contain potential habitat for seven Florida-listed species plus the general assemblage "wading birds." Our analysis shows that they would not be conserved under current strategies and budgets in time to avoid their development. From the parcels database, we can see that the land is currently ranchland, totaling 4,600 acres. It is owned largely by three people and one development company, with a current assessed value of just over 100 million dollars, or about $22,000 per acre (Figs. 4.10 and 4.11).

13 Limitations and Caveats

While we believe the overall SRP methodology to be relatively robust given existing available input data and models, in the case of Florida several major limitations are important to acknowledge. The first is that while we have dynamically simulated sea level rise and human settlement patterns under climate change, we have not been able to incorporate dynamic models of vegetation under such changes. Similarly, because we did not have access to the underlying data sets and model logic used to create potential habitat maps, so we could only consider the direct replacement of current habitat by urban uses. It is important to note that these analyses did not consider adjacency or population fragmentation impacts which may have existed in the original models. At the time this work was conducted, essentially all of the biological resource maps and models available in this region embedded assumptions of climate stationarity.

Climate envelope and vegetation succession modeling work is currently being undertaken by other research groups in this region (Best R 2010, Ongoing climate change-related projects in the Greater Everglades, Personal communication) and its integration using the SRP method would be a very important improvement. In other regions where such work has been done, the projected spatial shifts in vegetative communities have been significant. The SRP methodology would easily accommodate such information, but the process of updating hundreds of vegetation and species models to be climate-sensitive will literally take years.

A second general set of limitations relate to terrain and hydrology. While we would like to be able to use high-resolution LIDAR-derived terrain elevation information to assess sea level rise, such information is not uniformly available across the study area. In particular subregions, we have compared LIDAR-derived terrain elevations with our USGS National Elevation Dataset data. While magnitudes differ slightly, the overall pattern described here remains.

Similarly, dynamic modeling of storm surge using models such as SLOSH (Mercado 1994) can yield a significantly more detailed picture of the risks in coastal areas. Initial indications are that such methods can yield significantly more challenging circumstances, much further inland than static coastal sea level rise methods might indicate. A more detailed investigation of sea level affects would also likely include an integrated ground and surface water model. Again, such modeling could not be incorporated because it was not uniformly available across the region.

The level of spatial modeling conducted here is indicative of vulnerabilities, and has the considerable virtue of being feasible to implement for this and most regions using only existing public data sources. With this comes the danger of underestimating complex wildlife habitat responses and hydrological issues which represent serious knowledge gaps in the literature.

14 Discussion

SRP methods vary significantly from prior work in this field in that we seek first to simulate and understand the spatial context within which conservation planning must act, and only then simulate conservation activities. We consider multiple forms of land use and land cover change, as well as sea level rise. Unlike methods which seek to optimize conservation networks in terms of biotic conservation and static land cost or urbanization pressure (Ferrier and Wintle 2009; Watts et al. 2009) we use a rule-based allocation method with fixed conservation budgets and a simple "greedy" algorithm. It is clear that application of a more elaborate conservation optimization method could yield more efficient conservation strategies for the region. However, we note that our results are more dependent on our major initial assumptions than on subtleties of conservation strategy.

Conceptually, the SRP method is very distinct from other conservation planning approaches in that it does not presuppose that conservation intent is a uniformly-held social goal. Instead, we simulate a variety of actors, some potentially acting at cross-purposes to conservation. For example, our model for high-end housing asserts that such development is attracted to the fringe of conservation areas. If real estate market demand is present and other policies or legal interventions absent, our model predicts that allocation will occur relative to "willingness to pay." To us, conservation is more similar to the game of chess than to that of solitaire – the actions of others must be considered.

Our work extends systematic conservation planning to spatially and temporally simulate two of the most severe and common threats to biodiversity: climate change and human settlement patterns. Our initial hypothesis was that both of these factors were likely to be significant influences on conservation success in South Central Florida, and their joint simulation is appropriate. Based on the high percentages of coast refuges inundated, the human population displacements simulated and the impacts of both on simple ecological indicators, we believe that our results validate this hypothesis. More broadly, we have shown that a spatial resilience planning approach can provide information not available from methods which consider only biophysical changes.

When spatial simulation is used to allocate conservation and development decisions over time, it is clear that optimal strategies must consider not only space (the eventual proposed conservation network), but also time and management institutions. Under realistic estimates of conservation budgets and land prices, the phasing of conservation purchases becomes a key component of strategy: the purchase of lands absent development pressure wastes resources better spent elsewhere, but lands under such pressure are significantly more expensive.

In our simulations, several critical aspects of human behavior are also simulated. The first is human preferences for locating various non-conservation activities on the landscape, especially various densities of housing. The second is human behavior in the face of permanent inundation. Here, we used a simple model in which all socioeconomic classes retreat equally from SLR. However, the same modeling approach could also be used to model different social responses to SLR. For example, under some scenarios, one could imagine wealthy people remaining largely along the coastline and re-enforcing existing buildings, middle income segments moving inland, and lower income groups staying in place and being at highest risk. A more positive aspect of human behavior to contemplate is generosity in supporting conservation, in the form of voluntary conservation practices. In recent years, private conservation has blossomed. For example, in the case of the Nature Conservancy, voluntary conservation easements rather than purchase agreements now account for the majority of conservation lands acquisition. This practice provides significantly more land per dollar, but also has different restrictions than conventional free simple purchases. There is a strong need to consider these aspects more carefully in future conservation simulation work.

While we unavoidably must make some important simplifying assumptions, our results nonetheless reveal some strategically significant findings. First, we find that the land area likely to be lost to sea level rise exceeds historic and current conservation budgets. This implies that only to maintain current levels of gross land under conservation management we must significantly increase the rate and the effectiveness of conservation acquisition. Second, we find that existing conservation strategies lack the temporal detail necessary to organize strategic interventions into land markets before other forces convert land to development. In particular, we show that under existing and likely resource constraints, current strategies do not maintain a cohesive conservation network likely to be robust under climate change.

The framework used here produces outputs in two forms which can be immediately incorporated into current management and planning. It produces cartographically mapped information which indicates priority areas which are sensitive and well as insensitive to varying scenario assumptions. And it generates locally-scaled strategic information on the relative effectiveness of particular conservation strategies. In other words, it produces "actionable information" in forms currently used by current institutions, but based on dynamic rather than static analyses.

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