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Decision analysis for species preservation under sea-level rise

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ABSTRACT

Sea-level rise is expected to dramatically alter low-lying coastal and intertidal areas, which provide important habitat for shoreline-dependent species. The Snowy Plover (*Charadrius alexandrinus*) is a threatened shorebird that relies on Florida Gulf Coast sandy beaches for nesting and breeding. Selecting a management strategy for the conservation of this species under sea-level rise is a complex task that entails the consideration of multiple streams of information, stakeholder preferences, value judgments, and uncertainty. We use a spatially explicit linked modeling process that incorporates geomorphological (SLAMM), habitat (MaxEnt), and metapopulation (RAMAS GIS) models to simulate the effect of sea-level rise on Snowy Plover populations. We then apply multi-criteria decision analysis to identify preferred management strategies for the conservation of the species. Results show that nest exclosures are the most promising conservation strategy followed by predator management, species focused beach nourishment, and no action. Uncertainty in these results remains an important concern, and a better understanding of decision-maker preferences and the Snowy Plover's life history would improve the reliability of the results. This is an innovative method for planning for sea-level rise through pairing a linked modeling system with decision analysis to provide management focused results under an inherently uncertain future.

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1. Introduction

The effects of climate change and sea-level rise (SLR) on biodiversity are an issue of significant and widespread concern (Galbraith et al., 2002; Jetz et al., 2007; Menon et al., 2010; Sala et al., 2000). SLR is expected to dramatically alter low-lying coastal and intertidal areas that provide important habitat for a variety of shoreline-dependent species (Baker et al., 2006; Craft et al., 2009; Fish et al., 2005). Recent projections of habitat loss for shoreline-dependent birds at important staging and wintering coastal sites in the United States range between 20 and 70% (Galbraith et al., 2002). Florida has been identified as one of the states that is most vulnerable to climatic impacts (Clinton and Gore, 1993; National Assessment Synthesis Team, 2000; Noss, 2011). Shorebirds are especially susceptible to the effects of SLR in Florida because of the extensive coastline and low topography of the state. Sustaining the populations of species that depend on coastal habitats in the face of SLR requires that natural resource managers identify and implement ecosystem- and species-specific conservation measures.

Successful conservation plans require that natural resource managers sift through disparate types of information that have varying levels of importance to assorted stakeholders (Kiker et al., 2005). For example, when making a decision, a manager may have to consider budgetary constraints, public popularity, stakeholder values, and ecological tradeoffs. There are also many uncertainties with regard to the effects of SLR on natural resources to consider. First, the SLR predictions themselves are uncertain. Different projections for SLR by 2100 include 0.18–0.59 m (IPCC AR4 WG1, 2007),

Abbreviations: CI, confidence interval; DEM, digital elevation model; *F*, fecundity; *f*, number of fledglings; FWC, Fish and Wildlife Conservation; MaxEnt, maximum entropy; MCDA, multi-criteria decision analysis; S_j, juvenile survival rate; SLAMM, Sea Level Affecting Marshes Model; SLR, sea-level rise; SMAA, stochastic multi-criteria acceptability analysis; σ, standard deviation.

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0.62–0.88 m (Horton et al., 2008), 1.4 m (Vermeer and Rahmstorf, 2009), and up to 2 m (Allison et al., 2009; Pfeffer et al., 2008). These estimates are based on both historical and empirical methodologies and may incorporate or exclude the contribution from melting ice sheets. There are also uncertainties about how the natural environment will respond to the rise in sea level. Models and empirical relationships used to forecast the effects of SLR may simplify relationships, assume a steady state, and exist within data gaps and limitations. Finally, management strategies themselves may have uncertain consequences and cost–benefit tradeoffs. It is important to consider disparate types of information as well as their associated uncertainties to make robust management decisions. This process demands an organized and methodical toolset that can parse the often dissimilar and complex data within an adaptive management framework.

Multi-criteria decision analysis (MCDA) provides a systematic tool for identifying a preferred course of action when considering multiple forms of dissimilar information and differing value judgments among stakeholders (Kiker et al., 2005; Linkov et al., 2006). MCDA explores existing information and its relevance or limitations toward ranking potential management objectives. It provides a clear structure for decision-making in which management alternatives are identified, measures (or criteria) are established to evaluate the alternatives, and a decision matrix is developed to assess the alternatives according to the measures.

Management and conservation of threatened and endangered shoreline-dependent species in the face of SLR is particularly suited to the use of MCDA because of the diversity of stakeholders, information streams, and value judgments involved. In Florida, the effect of SLR on the Snowy Plover (*Charadrius nivosus*) is especially troublesome because of its threatened status, its dependence on shoreline habitat, and the habitat loss and increasing human disturbance currently occurring in areas for breeding and nesting, brood-rearing, wintering, and migratory stopover (Guilfoyle et al., 2006). Aiello-Lammens et al. (2011) used a linked modeling framework that integrates geomorphological, habitat, and metapopulation models to show that SLR will cause a decline in suitable habitat, carrying capacity, and populations for the Snowy Plover in Florida.

In response to the forecasts for SLR, resulting threats to beach habitat, and implications for the Snowy Plover, we assessed management alternatives for conservation of the species in Florida through MCDA. Specifically, the objectives of this research were to (1) use a linked modeling framework to assess Snowy Plover response to SLR, (2) define and simulate management alternatives for Snowy Plover protection, and (3) assess management alternatives within an MCDA framework using uncertain information. The decision methodology used here (1) defines the problem and objective, (2) identifies different management alternatives, (3) develops measures for assessing these alternatives, (4) assigns values and uncertainty to those measures under each alternative, (5) establishes a decision matrix for assessing alternatives using measures under specific goals, (6) evaluates a variety of weighting scenarios, and (7) synthesizes the results (after Kiker et al., 2008).

2. Methods

2.1. Study species and area

The Snowy Plover (*Charadrius alexandrinus*) is a small shorebird with populations throughout the temperate and subtropical regions of the world. The subspecies known as the Cuban Snowy Plover (*C. a. tenuirostris*) largely breeds and overwinters in Florida, where they rely on coastal sandy beaches for habitat (Lamonte et al., 2006). Males are responsible for chick-rearing, and females often produce two broods in one breeding season. The breeding season in Florida lasts from March to mid-summer. Breeding success for this population is dependent upon the availability of dune habitat as well as a lack of human development and disturbance (Lamonte et al., 2006). A loss of nesting habitat and widespread human disturbance, especially on coastal beaches used for recreation, has led to a decline in the population of the Snowy Plover on both the western and eastern US coasts (Lamonte et al., 2006; Colwell et al., 2005). The Florida Fish and Wildlife Conservation Commission (FWC, 2013) lists Snowy Plovers as threatened, and the US Shorebird Conservation Plan (2004) lists them as an Extremely High Priority for conservation.

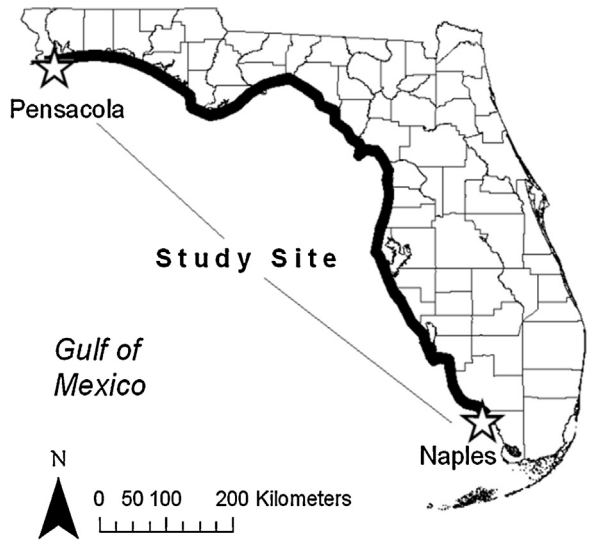

Fig. 1. Study site. The Florida Gulf Coast is marked in bold.

In Florida, Snowy Plovers are found along the Gulf Coast, mainly in the Panhandle and Peninsula (Aiello-Lammens et al., 2011). Therefore, the scale considered for this analysis is the Gulf Coast of Florida, including all of the populations of Snowy Plovers therein. Populations of plovers throughout the coast may mix and interbreed. Simulating connectivity captures a more realistic picture of the effects of management practices than focusing on single populations. The study area spans the Gulf Coast from Pensacola to Naples using a 10-km inland buffer and a 120-m grid resolution for simulations (Fig. 1) (Aiello-Lammens et al., 2011; Chu-Agor et al., 2012).

2.2. Linked modeling framework

A linked modeling framework has been previously established to simulate the response of the Snowy Plover to SLR in Florida (Aiello-Lammens et al., 2011; Chu-Agor et al., 2012). Within this framework, Sea Level Affecting Marshes Model (SLAMM; Warren Pinnacle Consulting, Inc.) simulates wetland migration, MaxEnt (Phillips et al., 2006; Phillips and Miroslav, 2008) simulates spatial habitat availability based on predicted spatial and temporal changes in wetland and shoreline habitats, and RAMAS GIS (Akçakaya, 2005) simulates Snowy Plover population changes based on the predicted habitat suitability maps. A detailed description of this linked modeling framework can be found in Aiello-Lammens et al. (2011) and Chu-Agor et al. (2012, 2013). We extend this framework to simulate the effects of management decisions on the Snowy Plover population under two SLR scenarios. For example, nourishment strategies aimed at augmenting beach habitat can be simulated in SLAMM, and nest exclosures aimed at