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Incorporating uncertainty about species' potential distributions under climate change into the selection of conservation areas with a case study from the Arctic Coastal Plain of Alaska

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ABSTRACT

This analysis presents a conservation planning framework for decisions under uncertainty and applies it to the Arctic Coastal Plain of Alaska. Uncertainty arises from variable distributional shifts of species' ranges due to climate change. The planning framework consists of a two-stage optimization model that selects a nominal conservation area network in the first stage and evaluates its performance under the climate scenarios in the second stage. The model is applied to eleven at-risk species in Alaska including the threatened Spectacled Eider and Steller's Eider sea ducks and the polar bear. The 109th United States Congress and 2008 federal budget proposed opening for oil and gas development the "1002 Area" of the Arctic National Wildlife Refuge, which intersects the Plain. This analysis finds that, if Arctic Alaska experiences 1.5 °C of warming by 2040 (as predicted by the Intergovernmental Panel on Climate Change's A2 scenario), then potential habitat will decrease significantly for eight of these at-risk species, including the polar bear. This analysis also shows that there is synergism between oil and gas development and climate change. For instance, climate change accompanied by no development of the 1002 Area results in an increase of potential habitat for Steller's Eider. However, if development accompanies climate change, then there is a 20% decrease in that area. Further, this analysis quantifies the tradeoff between development and maintenance of suitable habitat for at-risk species.

1. Introduction

Optimization models are often used to design conservation area networks, which are sites administered to protect threatened species and other components of biodiversity (reviewed in Sarkar et al., 2006). Traditionally, these models have been *time–static* insofar as they have assumed that all of the areas in a nominal conservation area network are put under a conservation plan at the same time, and *deterministic* in the sense that model parameters such as the locations of biodiversity surrogates (such as species or habitat types) and the budget for purchasing land do not have any explicit uncertainty associated with them. However, the importance of incorporating multi-stage predictions about future states of the landscape into conservation planning has been recognized since the mid-1990s. In 1994, an analysis of multi-decadal data on

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species' distributions in the Ingleborough limestone pavements in the United Kingdom demonstrated that if such predictions are not available to the decision-maker during the initial selection of conservation areas, by the final stage, species' turnover and extinction may have significantly decreased the biodiversity contents of areas put under a conservation plan at the first stage (Margules et al., 1994). In the last four years, the inclusion of future climate scenarios in the prioritization of conservation areas has also received increasing attention (Araújo et al., 2004; Pyke and Fischer, 2005; Hannah et al., 2007). The theoretical contribution of this study is to present a framework for multi-stage conservation decision-making under uncertainty that is tractable for problems of the size encountered in realistic planning exercises. The applied aspect of this study is to use this model to develop a nominal conservation plan for the Arctic Coastal Plain in Alaska's North Slope Borough. Uncertainties due to climate change–induced changes in species' distributions are incorporated into this analysis. Northern Alaska is a particularly appropriate setting for a planning exercise about climate change because annual mean climatic warming in the Arctic is predicted to exceed mean global warming and the effect of projected decreases in the extent and thickness of sea ice on fauna such as the polar bear may be profound (Schliebe, 2006; IPCC, 2007).

The Arctic Coastal Plain consists of 49,753 km^2 of drainage basins of rivers that flow from the Brooks Range into the Beaufort and Chukchi Seas (Duffy et al., 1999). The mammal fauna of the Plain includes the gray wolf *Canis lupus*, the brown bear *Ursus arctos*, four caribou *Rangifer tarandus granti* herds, including the Porcupine Herd with 123,000 individuals, and 1500 polar bears *Ursus maritimus*, which are classified as "vulnerable" by IUCN and proposed for listing as "threatened" by the United States Fish and Wildlife Service (Schliebe, 2006). From 10 May to 2 August the sun is never below the horizon on the Plain. During this time, hundreds of thousands of individuals of 230 bird species also migrate there from Africa, the Americas, and Asia to nest or molt (Troy, 1985; National Research Council,, 2003). Two sea duck species that breed on the Plain are listed as "threatened" under the Endangered Species Act: the Spectacled Eider *Somateria fischeri* and Steller's Eider *Polysticta stelleri* (Petersen et al., 2000; Fredrickson, 2001). Ten of the bird species that breed on the Arctic Coastal Plain are also included in Audubon Watchlist 2002, a reliable system for ranking North American birds based on extinction risk (Dunn, 2002) that uses a methodology similar to the IUCN Red List for birds (Stattersfield et al., 2000). Five of these bird species are also classified as "species of high concern" by a working group of shorebird experts at the United States Fish and Wildlife Service and United States Geological Survey because of declining populations (Supplementary Material, Table 1 (Alaska Shorebird Working Group, 2000)).

Development on the Arctic Coastal Plain consists largely of oil and natural gas extraction. Since 1977, 12 billion barrels of oil have been extracted from more than 2000 wells north of the Brooks Range, most near Prudhoe Bay. This constitutes 20–25% of United States oil production and provides taxes and royalties that make up 85% of the budget of the state of Alaska (Gilders and Cronin, 2000). On the Arctic Coastal Plain, 7011 ha of tundra are covered by gravel associated with oil development and an additional 4300 ha are subject to this development's indirect effects, including flooding, dust-killed vegetation, and thermokarst (National Research Council,, 2003). In March 2006, a 5000 barrel crude oil spill, the largest in North Slope history, occurred in the Western Operating Area of Prudhoe Bay (Marshall, 2006). The recovery of Alaskan tundra from such spills requires 600 years for mesic sites and up to 1200 years for marsh sites (National Research Council,, 2003). Subsequent tests of the Eastern Operating Area led to the shutdown of Prudhoe's 400,000-barrel per day production on 6 August 2006. It is estimated that when oil production at Prudhoe Bay ceases to be economically feasible, around 2040, the cleanup of oil facilities will cost 10 billion USD (US Government Accountability Office, 2002).

The 1002 Area of the Arctic National Wildlife Refuge (627,300 ha) is the sole protected area that intersects the Arctic Coastal Plain. The United States Alaska National Interest Lands Conservation Act of 1980 prohibited oil development elsewhere in the Refuge but authorized study of the 1002 Area's potential for oil production, which is now estimated at 7.7 billion barrels (Schuenemeyer, 2002; Montgomery, 2005). The United States House of Representatives in HR 2491 in 1996, HR 4 in 2001, HR 6 in 2003, and HR 5429 in 2006, and Senate in S. 1932 in 2005 have passed bills to open the 1002 Area to oil development. In addition, the Fiscal Year 2008 budget proposed by the Executive Office of the President assumes 7 billion USD in oil lease revenues from the 1002 Area (Corn et al., 2007).

These proposals are inimical to biodiversity conservation in the Arctic Coastal Plain. Development of the 1002 Area may result in population declines in the polar bear, which shows greater preference for the 1002 Area for denning than other nearby areas, and may also reduce calf survival in the Porcupine Herd caribou (Stirling, 1990; Amstrup and Gardner, 1994; McCabe, 1994). Steller's Eider is susceptible to oil spills during molt because of its gregarious nature and because, as a bottom feeder, it is likely to become covered with oil each time it surfaces (Blood, 1977; Bustnes, 1997). The eastern Arctic Coastal Plain, which includes the 1002 Area, also includes breeding grounds for the Spectacled Eider *Somateria fischeri*, which is federally listed as "threatened" because of a 96% decline in the Alaska population since 1957 (Petersen et al., 2000). Oil development is also likely to impact negatively other birds of conservation concern on the Arctic Coastal Plain. The Black Brant Goose *Branta bernicla nigricans* experiences low nest success in oil fields and requires an undisturbed environment to regrow feathers during molt (Taylor, 1995; Sedinger and Stickney, 2000).

Assessment of the effects of oil and gas development in the future must also take climate change into consideration because the Arctic Coastal Plain is experiencing surface warming and concomitant increased vegetation greenness and shrub abundance (Lachenbruch and Marshall, 1986; Jia et al., 2003, 2006; Bunn and Goetz, 2006). This warming is predicted to result in population declines in both the Porcupine Herd caribou and the polar bear (Eastland and White, 1990; Stirling and Derocher, 1993; Stirling et al., 1999). The United States District Court for the state of Alaska recently ruled that there was insufficient scientific data on the combined effects of global warming and oil and gas development on the Plain