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Conservation in a social-ecological system experiencing climate-induced tree mortality

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ABSTRACT

We present a social-ecological framework to provide insight into climate adaptation strategies and diverse perspectives on interventions in protected areas for species experiencing climate-induced impacts. To develop this framework, we examined the current ecological condition of a culturally and commercially valuable species, considered the predicted future effects of climate change on that species in a protected area, and assessed the perspectives held by forest users and managers on future adaptive practices. We mapped the distribution of yellow-cedar (*Callitropsis nootkatensis*) and examined its health status in Glacier Bay National Park and Preserve by comparing forest structure, tree stress-indicators, and associated thermal regimes between forests inside the park and forests at the current latitudinal limit of the species dieback. Yellow-cedar trees inside the park were healthy and relatively unstressed compared to trees outside the park that exhibited reduced crown fullness and increased foliar damage. Considering risk factors for mortality under future climate scenarios, our vulnerability model indicated future expected dieback occurring within park boundaries. Interviews with forest users and managers revealed strong support for increasing monitoring to inform interventions outside protected areas, improving management collaboration across land designations, and using a portfolio of interventions on actively managed lands. Study participants who perceived humans as separate from nature were more opposed to interventions in protected areas. Linking social and ecological analyses, our study provides an interdisciplinary approach to identify system-specific metrics (e.g., stress indicators) that can better connect monitoring with management, and adaptation strategies for species impacted by climate change.

1. Introduction

Species distributed across a variety of land designations and management regimes are impacted by climate change (Root et al., 2003; Araújo et al., 2004). Future changes in climate will likely result in ecological responses, including climate-induced forest mortality that can affect ecological communities, ecosystem function, ecosystem services (Anderegg et al., 2013), and shifts in species distributions (IPCC (Intergovernmental Panel on Climate Change), 2007; Allen et al., 2010). These dynamics challenge stewardship of protected areas. Setting aside lands to protect biodiversity or historical communities may no longer be sufficient to sustain species vulnerable under climate change (Araújo et al., 2004; Heller and Zavaleta, 2009) yet, many resource managers still follow management plans that do not account for climate change (Pyke et al., 2008).

Conservation strategies need to incorporate climate-change scenarios and include lands outside of protected areas that are actively managed for human use (Bengtsson et al., 2003; Kareiva, 2014). Such approaches include expanding reserves (Beier and Brost, 2010), creating dynamic reserves that mimic disturbance regimes (Bengtsson et al., 2003), and assisting migration (McLachlan et al., 2007). Much information on climate-change impacts, however, focuses at global and regional scales with a high degree of uncertainty and is too broad to inform management of specific places (Hobbs et al., 2010). This is particularly true for precipitation projections (Ashfaq et al., 2013), which are critical for plants.

Abbreviations: GLBA, Glacier Bay National Park and Preserve; WCYW, West Chichagof-Yakobi Wilderness; PAS, precipitation as snowfall.

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To inform management and conservation in a changing climate, Hagerman and Satterfield (2014) call for interdisciplinary, comparative, place-based empirical inquiry and a greater integration of natural and social sciences. A social-ecological system approach enables analysis of interactions among a variety of factors (Ostrom and Cox, 2010). Social systems may self-organize for adaptation through individuals responding to environmental change (Folke et al., 2005).

Acting within their current management capacity, or interpreting laws, policies, and regulations, managers of public lands in protected status increasingly need to experiment with interventions (Cole and Yung, 2010). These management decisions require understanding current and expected ecological changes, as well as human values, to be sustained (Hobbs et al., 2010). How people respond to climate-change impacts depends on factors such as knowledge about the impacts occurring (Folke, 2006; Sundblad et al., 2009), values (Adger et al., 2009), and perceptions of risk (Grothmann and Patt, 2005). Without a legal structure directing adaptive management, the social license for interventions must be considered.[1]

Our study's purpose was to examine the current ecological condition of a valuable species, consider the predicted future effects of climate change on that species in a protected area, and assess the perspectives held by forest users and managers on future adaptive practices. Our study focuses on yellow-cedar (*Callitropsis nootkatensis*; D. Don; Oerst. ex D.P. Little), a tree species experiencing widespread climate-induced dieback across actively managed public lands and federal protected areas in southeast Alaska. We mapped the previously unknown distribution of yellow-cedar in Glacier Bay National Park and Preserve (GLBA), examined the health status of yellow-cedar and its associated thermal regimes, and modeled future vulnerability for the species within GLBA under future climate scenarios. We then interviewed forest users and managers to understand their perceptions of climate-change impacts as warranting new management practices and to understand how underlying values and other emergent factors (e.g., barriers to adaptation, views of protected areas) influenced their perspectives. We developed a framework with insight into adaptive management strategies and diverse perspectives on interventions in protected areas for climate-change-impacted species.

1.1. Organizing framework

Our organizing framework (Fig. 1) integrates social and ecological variables relevant to adaptive management and conservation for species experiencing climate-induced impacts occurring across land designations. The framework describes that, typically, a protected area is established for specific conservation objective(s). Given relatively minimal climate-induced impacts or awareness of those impacts at the time, climate change was not considered in management and conservation plans. Observational studies later document climate-change impacts to a particular species; modeling indicates continued future impacts across land designations. Ecologists propose management alternatives to current practices, such as shifting protected-area boundaries or various interventions.

We suggest that decision-making to adopt new management practices, which is often informed by ecological knowledge and understanding, is also influenced by use values—benefits people obtain directly (e.g., through extractive or non-extractive uses) or indirectly (e.g., through aesthetic appreciation) (Gee and Burkhard, 2010). Individual perceptions of human–nature relationships in protected areas (i.e., what we term as "views of protected areas") may also influence their perspectives on adaptive management strategies.

[1] In the business literature, "social license" describes the extent to which a corporation is constrained to meet people's expectations and avoid activities perceived as unacceptable (Gunningham et al., 2004). We use it in reference to individuals' support of, or opposition to, adaptive strategies.

1.2. Background

Yellow-cedar's widespread mortality, or *decline*, covers nearly 200,000 ha of mixed-conifer forests in southeast Alaska (Lamb and Winton, 2011; Hennon et al., 2012). The causal mechanism linking the species dieback to climate change involves early springtime thaws that trigger dehardening and reduced snowpack that exposes shallow roots to sudden cold events (Schaberg et al., 2005, 2008, 2011; D'Amore and Hennon, 2006; Beier et al., 2008; Hennon et al., 2012). Currently, no federal policy mandates active climate-related interventions for the species (Appendix A). However, the species is in review for listing under the Endangered Species Act (U.S. Department of the Interior, 2015).

Our study area encompasses southeast Alaskan communities adjacent to public lands managed by the USDA Forest Service and the U.S. National Park Service, yellow-cedar forests in GLBA, and the West Chichagof-Yakobi Wilderness (WCYW). Part of a 10-million-hectare World Heritage site, GLBA is located at the northern extent of the contiguous yellow-cedar population distribution and just north of the current latitudinal limit in WCYW where mortality persists in the Tongass National Forest (Tongass) (Oakes et al., 2014) (Fig. A1).

2. Methods

Our study uses social and ecological data collected across multiple scales to assess: (1) the current ecological condition and future vulnerability of yellow-cedar in the study area, (2) perspectives on adaptation strategies, and (3) the influence of views of protected areas and values on whether future changes may warrant shifting management paradigms (Fig. 2).

2.1. Vegetation

To examine the health status of yellow-cedar populations, we collected data at 18 fixed-radius plots (GLBA, $n = 10$; WCYW, $n = 8$) at locations randomly generated in coastal forests that appeared unaffected by yellow-cedar decline in aerial and boat surveys (Appendix B). WCYW plots describe healthy forests adjacent to forests affected by the dieback at its current latitudinal limit for comparison to healthy GLBA plots (Oakes et al., 2014). The study area within the two management units was selected to provide insight into the condition of yellow-cedar north of where dieback occurs.

We counted live yellow-cedar saplings (<2.5 cm dbh and ≥1 m height). For each yellow-cedar tree (≥2.5 cm dbh), we recorded dbh, height, condition (dead or live), canopy position (suppressed, intermediate, codominant, dominant, emergent) and strata (Oliver and Larson, 1996). We used three possible stress indicators for live yellow-cedar trees: crown ratio (distance between top and bottom of live crown divided by tree height), flagging (percentage of deteriorated foliage), and crown fullness (percentage of live crown occupied by foliage) (Fierke et al., 2011; USDA Forest Service, 2014). We used 10% increments for ocular estimations of fullness and flagging.

Diameter distributions were constructed to compare the structure of the yellow-cedar population (saplings, dead and live trees) between GLBA and WCYW. We calculated the crown ratio for each yellow-cedar tree as live crown length divided by tree height. For each plot, we calculated average percent flagging, live crown, and crown ratio from all live yellow-cedar trees. To distinguish stressed trees from healthy trees with little flagging (considered normal foliage senescence), we used a threshold of ≥20% flagging (USDA Forest Service, 2014). A binomial model was used to test the effect of location (GLBA, WCYW), canopy position, and the interaction between location and position on the probability of a tree displaying ≥20% flagging. Emergent ($n = 2$) and dominant ($n = 30$) categories were combined for this analysis. We used Kruskal–Wallis tests (alpha = 0.05) to test for significant differences between locations at the plot level (tree and sapling density, proportion of trees with ≥20%