Biological Conservation 192 (2015) 276–285

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

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

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ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 10 September 2015
Accepted 14 September 2015
Available online xxxx

Keywords:
Climate change adaptation
Forest dieback
Perspectives on intervention
Conservation triage
Protected areas
Callitropsis nootkatensis

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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http://dx.doi.org/10.1016/j.biocon.2015.09.018
0006-3207/

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.

1.2. 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%

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[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.

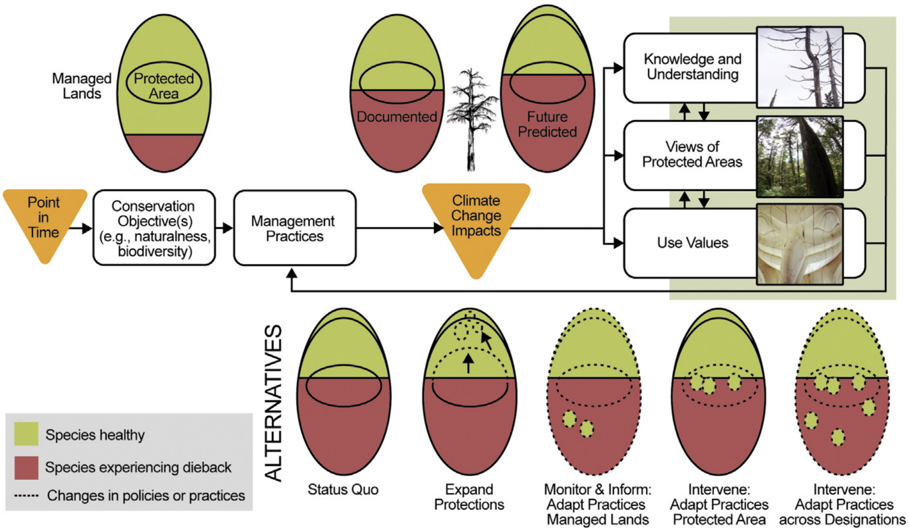

Fig. 1. Organizing framework that integrates social and ecological variables relevant to adaptive management and conservation of a climate-sensitive species. The framework identifies key social and ecological factors that influence perceptions of adaptive practices (management alternatives to the status quo) across the species distribution (large oval) in protected areas and actively managed lands. Extended oval indicates possible range expansion to higher latitudes or elevations.

flagging, average crown ratio, average flagging, and average crown fullness).

2.2. Temperature

Hourly soil and air temperature data (at 7.5 cm depth and 2 m height) were collected using Hobo® Tidbit and Pendant sensors at sites that appeared healthy in GLBA and WCYW (June 2011–August 2013) to compare thermal regimes from a yellow-cedar perspective (Appendix B). We developed a diverse set of local climate metrics (Garcia et al., 2014) based on the literature relevant to climatic risk factors for yellow-cedar decline (e.g., reductions in snow cover may cause yellow-cedar roots to deharden by March, leaving them vulnerable to low spring temperatures (Schaberg et al., 2011); soil temperature < -5 °C is lethal to yellow-cedar by causing root freezing injury (Schaberg et al., 2008)). The "first cool-down event" metric recorded the number of days between October 1st and the first soil temperature transition from ≥ 2.0 °C to < 1.0 °C. To compare soil temperatures during this cooling period, we calculated the soil temperature variability in fall (October 17 to November 17). "Number of warm-up events" counted the number of times that soil temperature transitioned from < 1.0 °C to ≥ 2.0 °C between September 1 and May 31. "Date of last warm-up" indicated when snow cover dissipated, estimated by the date of final spring soil temperature transition from < 1.0 °C to ≥ 2.0 °C. "Possible exposure days" counted the number of days that air temperatures dropped below 0 °C after the date of last warm-up. "Total soil degree days" above 0 °C for spring were accumulated from January 1 to April 1 to compare the amount of springtime warming between areas. Mean, maximum, and minimum spring (March 12 to April 12) soil temperatures, and mean spring daily range were used to compare exposure between the two areas during this transitional time. Exact date ranges for each metric were selected to minimize missing data across sites and years.

To explore differences in temperature metrics between GLBA and WCYW, we conducted permutation tests on each metric independently. In each case, we permuted site labels within the year to maintain annual

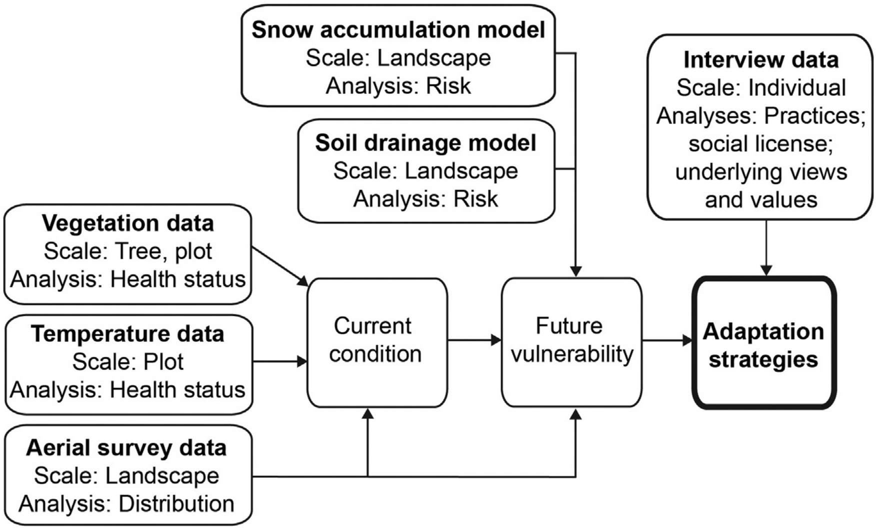

Fig. 2. Social-ecological data and models used in study. Scale and focus of analyses are listed for each dataset to illustrate interdisciplinary methods used to inform adaptation strategies.

correlation structure. All temperature and vegetation analyses were performed in R (R Development Core Team, 2013).

2.3. Yellow-cedar distribution

To assess status of yellow-cedar within GLBA and map its previously unknown distribution, we conducted aerial surveys (June–July 2012). Observers sketch-mapped polygons as: live yellow-cedar present (10–100% of the stand); live yellow-cedar scarcely present (<10% of the stand); no yellow-cedar in the stand; stand with concentrated yellow-cedar mortality. We modeled the data to fill land cover gaps between the polygons and existing, continuous land cover classes (Boggs et al., 2008). This method enabled a more accurate mapping of yellow-cedar distribution by identifying land cover classes that commonly included yellow-cedar, and modeling the sketch-mapped data to those continuous classes within a limited distance of the flight line (Appendix B).

2.4. Future vulnerability

We performed a climate vulnerability assessment (Rowland et al., 2011; Thomas et al., 2011) to evaluate the impact of future (present to 2099) environmental conditions on yellow-cedar in GLBA. Considering the interactions between future climate change and species' sensitivities (Dawson et al., 2011), we captured the mechanistic pathway of yellow-cedar decline using two critical risk factors: snow and soil drainage (D'Amore and Hennon, 2006; Hennon et al., 2012). As the bioclimatic envelope approach is largely focused at range edges, we used an assessment based on known risk factors to consider vulnerability at finer spatial scales where yellow-cedar occurs. The mapped yellow-cedar distribution was used as a basis for modeling that incorporated a soil drainage index and precipitation as snowfall (PAS). Vulnerability classes (low, medium, high) were developed through analysis and interpretation of the relative soil drainage and PAS on the landscape as they relate to conditions where dieback currently occurs (Appendix B).

2.5. Management perspectives

We conducted in-person interviews with 45 forest users and managers (April–May 2013). The semi-structured interviews, which were conducted at each interviewee's place of preference (e.g., work, home), were designed to explore: (1) adaptive practices related to yellow-cedar decline; (2) the social license for adaptive management strategies by qualitatively assessing support for specific practices; and (3) the underlying values and other emergent factors that shape individual perspectives on specific practices. Our sample included “users,” specifically residents who use the forest in diverse ways across land designations, and “managers,” specifically those who work within the Tongass governance system or manage Alaska Native land. A combination of chain and intensity sampling (Patton, 2002) was used to select individuals representing a breadth of relationships to forests and uses of forest resources (e.g., recreation and tourism, customary and traditional uses, forest products) (Appendix B; Fig. B1).

For this paper, our analysis focused on data from 26 items (Appendix B; Table B1) within a longer interview protocol (Patton, 2002). The protocol explored knowledge and attitudes about the dieback, use values related to unaffected and affected forests, ways in which forest users and managers are adapting to impacts, and perspectives on future adaptive management practices. We asked participants to consider the possibility that the dieback may emerge in additional areas in southeast Alaska and asked whether they would want to see new management strategies for yellow-cedar forests on lands under active management and located in protected areas. We used probes to explore interviewees' perspectives on specific management practices (e.g., planting, protecting yellow-cedar where it may be more likely to survive) and let discussion related to other practices emerge.

We audio-recorded and transcribed interviews verbatim. We used NVivo v10.0 (QSR International) to analyze data through selective and open coding (Creswell, 2012). Selective coding was used to examine content in broad a priori themes: management, conservation, protected areas, and use values. Open codes were used to explore emergent perspectives about yellow-cedar management if the dieback were to spread, by coding for opinions (i.e., support or opposition) regarding specific practices, and to identify patterns of other emergent factors (e.g., perceived barriers, views of protected areas) associated with those perspectives. Open coding was also used to identify content related to views of the relationship between humans and nature in protected areas and the value of protected areas. We classified support (low, moderate, high) for each practice based on the range of opinions expressed.

3. Results

3.1. Current ecological conditions and future vulnerability

3.1.1. Population structure and stress indications

Total yellow-cedar basal area (live and dead trees) was not significantly different between plots in WCYW and GLBA (39.01 ± 6.27, 40.78 ± 8.96 m^2/ha, respectively) ($p = 0.48$), nor was total yellow-cedar tree density (2310 ± 969, 1653 ± 814 trees/ha) ($p = 0.18$). Standing dead trees constituted 25% of the yellow-cedar observations in WCYW and 19% in GLBA. Dead yellow-cedar comprised a significantly greater proportion of the total yellow-cedar basal area in WCYW than in GLBA ($p = 0.0077$), but the density of dead yellow-cedar trees was not significantly different between WCYW and GLBA (611 ± 360, 381 ± 229 trees/ha) ($p = 0.12$). The majority of dead yellow-cedar trees observed in GLBA were suppressed trees in the canopy (67%). WCYW dead yellow-cedar trees occurred across tree canopy positions: suppressed (21%), intermediate (25%), co-dominant (33%), and dominant (16%). Yellow-cedar tree diameters in both locations followed a reverse-J size-frequency distribution (Appendix C; Fig. C1) often associated with multiaged stands (O'Hara, 2014). We found no difference in sapling density between locations ($p = 0.96$).

Despite the similar structure of the live tree population by size class in WCYW and GLBA forests, signs of tree stress differed importantly. The proportion of trees with ≥20% flagging was significantly lower in GLBA than WCYW ($p < 0.001$) (Fig. 3(a)), as was average percentage flagging ($p < 0.001$) (Fig. 3(b)). Crowns were significantly more full in GLBA ($p = 0.027$) (Fig. 3(c)). Average proportion of trees with dead tops in WCYW was 0.12 ± 0.1, whereas only two trees with dead tops were observed in GLBA; however, the difference in average crown ratio was not significant ($p = 0.55$) (Fig. 3(d)). The tree-level logistic model indicated that there was a significantly lower probability of a tree with ≥20% flagging occurring in GLBA than in WCYW ($p < 0.001$) (Table C1). In WCYW, this flagging occurred across canopy positions. There was also a significantly higher probability of trees with ≥20% flagging occurring in the suppressed position, typical of normal understory tree attrition in multiaged stands, in GLBA ($p = 0.012$).

3.1.2. Thermal regimes

We observed similar seasonal trends in soil temperature across all plots: a dramatic fall cooling period, a cold winter punctuated by warming spikes, a variable early spring, and a gradual climb into warmer summer temperatures. No root-freezing events of <-5 °C (soil) were detected during the study period. Despite the general similarities in seasonal trends, when soil temperatures were examined using metrics directly relevant to the mechanism of decline (i.e., freeze-thaw exposure), we observed differences between plots in the two locations (Appendix C; Fig. C2). Spring mean and maximum soil temperatures were warmer and more variable in WCYW ($p < 0.001$). The more dramatic of these differences was in the maximums, which were, on average, 4.8 °C in WCYW versus 1.9 °C in GLBA. Spring minimum soil temperatures ($p = 0.08$) were also slightly warmer in WCYW. The

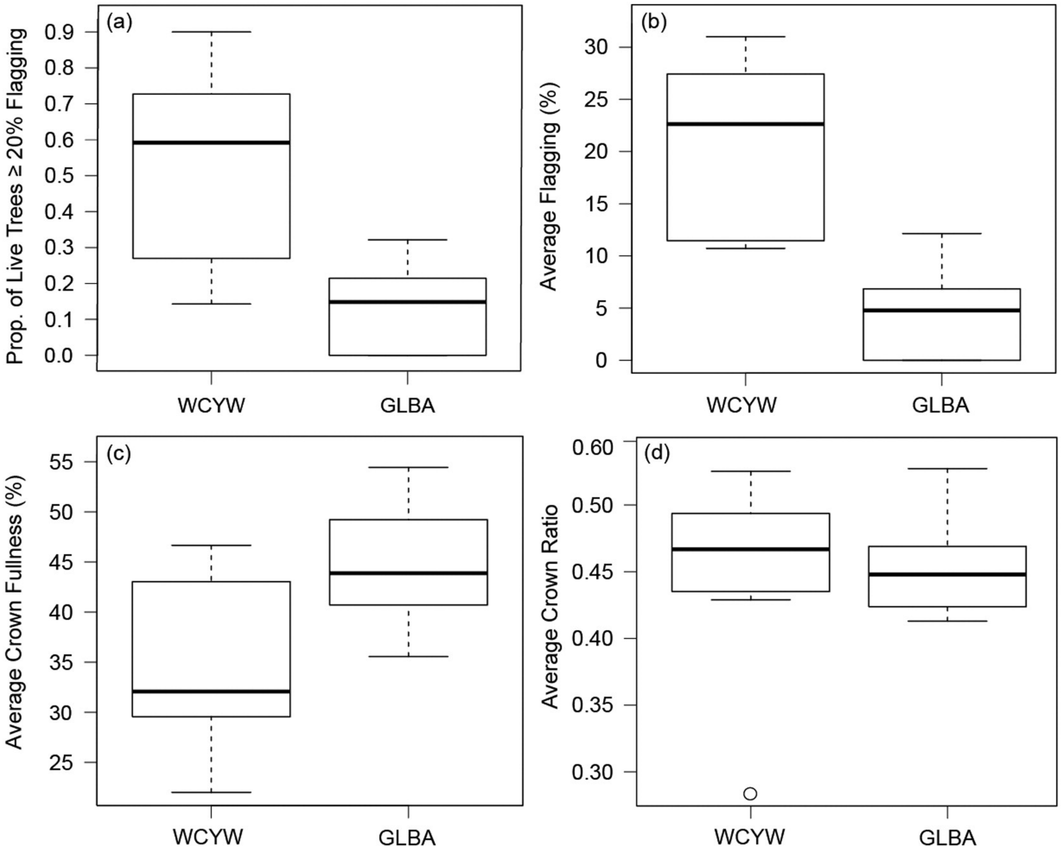

Fig. 3. Stress indicators compared between locations for all live yellow-cedar trees ≥ 2.5 dbh at each plot in WCYW ($n = 8$) and GLBA ($n = 10$). Comparisons include: (a) proportion of live trees with ≥20% flagging, (b) average flagging, (c) average crown fullness, and (d) average crown ratio. (Solid line indicates median value; boxes identify the center quartiles of the data; and whiskers designate one-and-a-half times the interquartile range).

muted spring thermal regime in GLBA was reflected in a mean spring soil daily range that was, on average, 0.46 °C less variable in GLBA than in WCYW ($p < 0.001$). The date of the last warm-up occurred, on average, 20.8 days later in GLBA ($p = 0.003$). On average, WCYW accumulated 47.9 more soil degree days before April 1 ($p = 0.02$). GLBA experienced an average of only 3.3 warm-up events, compared to 4.5 in WCYW; the difference was not significant ($p = 0.23$).

We also observed differences in metrics designed specifically to consider the potential for winter root damage. There were significantly fewer days in GLBA when tree roots might have been exposed to freezing temperatures after warm-up began. There were, on average, 9.8 possible exposure days in WCYW and only 2.6 in GLBA ($p = 0.032$). The average variability in fall soil temperature was 2.6 in WCYW, as compared to 1.6 in GLBA ($p < 0.001$). The first fall cool-down occurred on average of 15.8 days earlier in WCYW than GLBA; however, this was not a significantly difference ($p = 0.20$).

3.1.3. Distribution

Our aerial survey observations yielded 16,120 ha of yellow-cedar distributed across the outer coast of GLBA. Modeling of the sketch-mapped yellow-cedar occurrence to land cover classes yielded 23,968 ha (Fig. 4(a–b)), which we used to assess future vulnerability. No visible concentrated mortality, typically indicative of decline and easily detected ~85 km south of GLBA, was observed during the aerial survey flights.

3.1.4. Vulnerability

We found an expected increase of yellow-cedar forests with high vulnerability to dieback developing from east to west along the outer coast, and upward in elevation (3% in the 2020s; 27% by the 2080s). Low vulnerability dominates (79%) yellow-cedar forests in the 2020s, but is expected to reduce (to 42%) by the 2080s (Fig. 4(c), 4(d), 4(e)). By the 2080s, we found low vulnerability persisting in yellow-cedar forests located inland from the coast at the northerly extent of GLBA's yellow-cedar distribution and on lands at relatively high elevations eastward. Because soil drainage was assumed relatively stable through time, changes in vulnerability were driven by reductions in PAS under future climate.

3.2. Perspectives on adaptive management

3.2.1. Where to intervene

We identified a four-category typology of views of protected areas that emerged from the coding analysis and found these distinct views to be associated with contrasting perspectives on implementing new practices in protected areas (Table 1). Participants who perceived legal restrictions in protected areas, and those who perceived protected areas as "separate" from humans, commonly expressed strong opposition to protected-area intervention. In contrast, participants who perceived humans as "a part of" protected areas, and those who openly opposed protected-area designation, more commonly considered protected-area interventions favorably. Participants who opposed protected-area designation were working in the forest products industry or engaging in customary and traditional uses. These views of protected areas seemed to influence participants' perspectives on where to intervene (i.e., inside or outside protected-area boundaries).

3.2.2. How to intervene

Most participants supported some intervention on managed lands, but the specific practices they supported were associated with their use values (e.g., planting to ensure future harvests or other direct uses, or preserving healthy trees to protect intangible

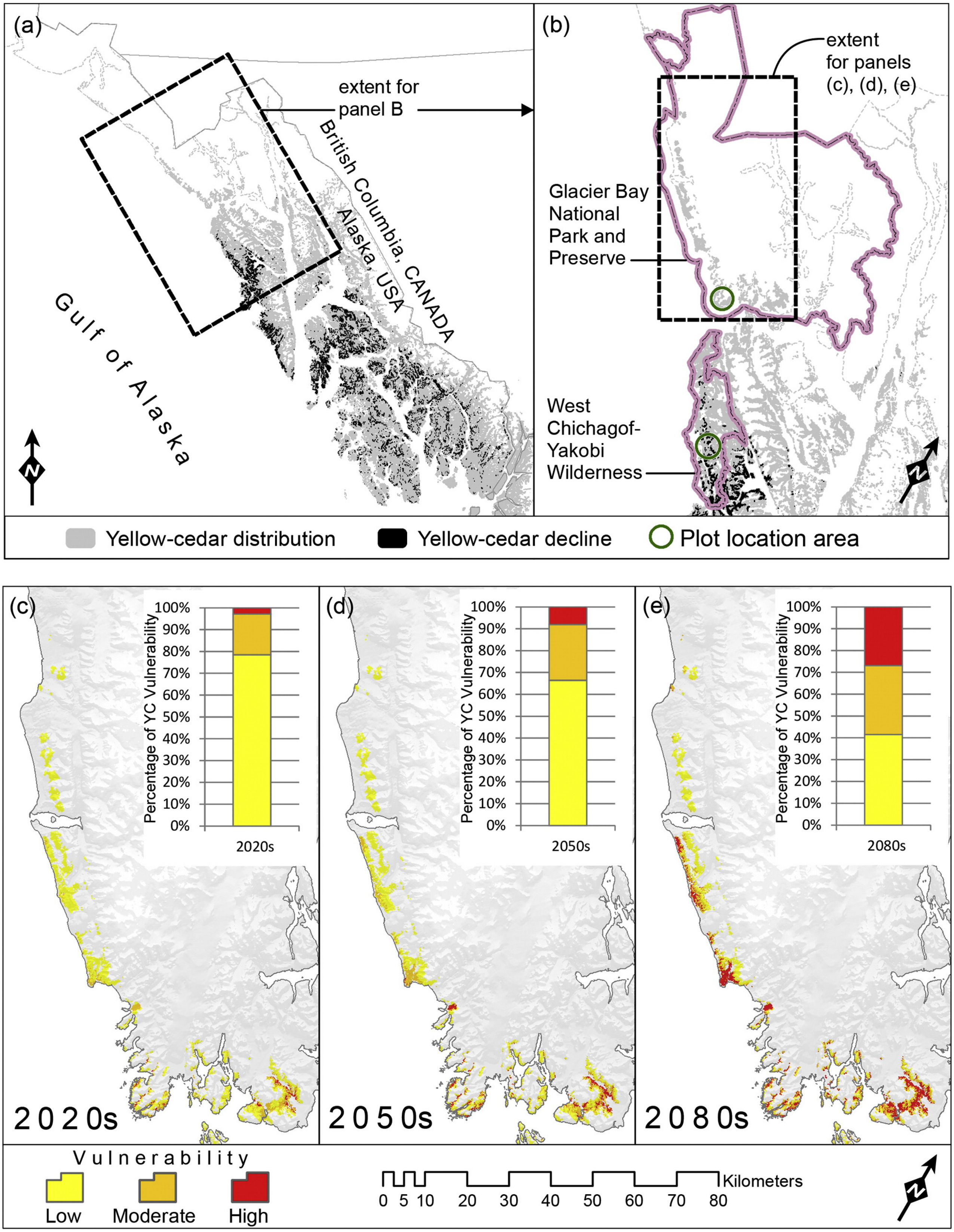

Fig. 4. Future vulnerability inside the protected area. Yellow-cedar distribution and existing decline (USDA Forest Service, 2010) in southeast Alaska (a); boundaries for GLBA and WCYW with plot locations in relation to yellow-cedar distribution and existing decline (b); percentage of yellow-cedar distribution in GLBA vulnerable to future climate-induced dieback (c, d, e). The future climate normals (2020s; 2050s; 2080s) span years 2010–2039, 2040–2069, and 2070–2099, respectively (Klassen and Burton, 2014).

Table 1
Views of protected areas held by study participants and associated perspective on new practices in protected areas.

View of protected areas	Description	Sample quotes	Associated perspective on protected-area intervention
Separate from humans	Perceiving protected area as natural, pristine, and separate from humans; humans are only visitors	"I see Wilderness as set aside, and that's where we just let Mother Nature do what she does." (Manager 10) "The wild country is a crucible of what the Earth is doing, and if we start messing with it in any fashion, we're screwing with it." (User 13)	No intervention, or preference for relatively less aggressive practices like monitoring (as opposed to actions like planting)
Integrated with humans	Perceiving humans as a part of nature, despite land designations	"My view is that you have to start seeing yourself as part of that Wilderness. We have to create what it is that we want to be a part of." (User 14) "Nothing is completely natural anymore." (Manager 9)	Intervention
Unwarranted designation	Opposing the establishment of protected areas; perceiving protected areas as severing human-environment relationships	"Wilderness is a curse word. I would rather people learn the value of what they're using as opposed to set aside." (User 1) "I don't think that exclusive set-asides always accomplish what we really want. I think they are the extreme opposite of massive clearcuts. To keep a sustainable forest, they fight one extreme with another." (User 12)	Intervention
Structured by laws, policies, and regulations	Perceiving laws, policies, and regulations as the determinants for human–environment relationships with protected areas; focusing on legally permissible actions, rather than personal views	"It's my understanding that [protected areas are] essentially off limits for management." (Manager 6) "There's a [legal] assumption that [protected areas] are conservation areas and that they serve as a snapshot of undisturbed areas." (Manager 7)	No intervention, or preference for practices perceived to be permissible under laws, policies, and regulations

values). Through core themes that emerged in discussion of practices, we found participants' perspectives on specific adaptive practices were also informed by the individual's knowledge about available "solutions" as alternatives to accepting the changes occurring; perceived efficacy of each practice given understanding of the cause of decline; perceived barriers, such as financial costs, institutional capacity, forest accessibility; and concern regarding setting precedent. As participants discussed site-specific planting and assisted migration, they commonly mentioned socio-economic barriers to action and questioned efficacy and agency capacity for implementation. These barriers were most commonly discussed in relation to managed lands, but also were explained similarly by the fewer participants who considered protected-area interventions.

3.2.3. Social license

We found relatively high levels of support for specific practices inside and outside protected-area boundaries (e.g., initiating monitoring programs in, and learning from, protected areas to inform practices on managed lands, and harvesting dead yellow-cedar on lands with a history of other land use (e.g., commercial logging) (Table 2). We found relatively low support for more aggressive interventions, such as planting, in protected areas. Participants commonly supported a management paradigm that included harvesting dead trees on managed lands in moderation. Of the 31 participants who discussed increasing protections for yellow-cedar from harvest or other uses, 11 expressed hesitant support, 17 clear support, and 3 opposition. Harvesting dead cedar was often perceived as a potential offset to harvest reductions that could result from implementing new protections in places where trees may be more likely to survive. Individuals supporting planting, assisted migration, or harvesting dead cedar commonly considered using several of these practices in a portfolio approach as experimental first steps in adaptation.

4. Discussion

4.1. Yellow-cedar in GLBA and adaptation strategies

Our study documents currently healthy yellow-cedar in GLBA and provides evidence for expected future climate-induced dieback. Neither the structure of the live tree population nor sapling regeneration varied significantly between forests inside and outside GLBA. Observed differences in crown fullness and flagging between locations, however, indicate symptoms of early onset of dieback in WCYW, extending north from stands where mortality comprises ~80% of yellow-cedar basal area (Oakes et al., 2014). Yellow-cedar trees may die slowly with crowns thinning over years (Shaw et al., 1985), but crown ratio does not appear to be an expression of stress. No exposure to soil temperatures <-5 °C occurred during the study timeframe; however, the observed differences in thermal regimes between the two locations indicated relatively greater, current risk to yellow-cedar in WCYW. Periodic injury (i.e., not annual) may induce yellow-cedar decline (Beier et al., 2008). The observed thermal differences help explain current signs of stress in WCYW and describe the climate conditions in GLBA relevant to future vulnerability. These metrics provide a tool for microclimate monitoring. Stress indicators could be used for ground-based monitoring of early decline onset in new initiatives inside protected areas or added to existing programs on actively managed lands. Our vulnerability modeling results suggest that dieback is expected to emerge in GLBA and that yellow-cedar will become less abundant in areas with insufficient snow cover. Because three of the six general circulation models selected (Appendix B; Table B4) incorporated the B1 scenario (relatively low emissions), these results represent a conservative estimate of vulnerability (Appendix D) that warrants consideration of adaptive practices.

The perspectives shared by forest users and managers suggest that the first steps in adaptation, with relatively high support, include initiating monitoring in protected areas; learning from protected areas to inform practices on managed lands; enhancing management collaboration across land designations; and using a portfolio of adaptive management practices on actively managed lands. This portfolio included experimental interventions, such as site-specific planting, assisted migration, and harvesting dead cedar, as well as expanding protections into actively managed lands to reduce harvesting where yellow-cedar may be more likely to survive. Experts who were interviewed about the implications of climate change for conservation frequently held diverse perspectives on common adaptive practices described in the literature (Hagerman et al., 2010). Our observed differences between support from users and managers on specific practices, and the patterns we found of associated use values with specific practices, also indicate the

Table 2
Management practices discussed by land designation and qualitative level of support for each practice amongst study participants.

Public land designation	Practice	Sample quotes	User support	Manager support
Protected areas	Initiate monitoring and learn (emergent)†	"In some ways, we learn from those [protected areas] and that may… inform how we work [on managed lands]." (User 7)	High	High
	Enhance cross-cultural collaboration (emergent)	"It's ridiculous to remove Tlingit [Natives] from the [protected-area] equation of land management…They could learn from us. How long have we been living with these trees?" (User 1) "We [Alaska Natives] have been doing research every day…When I go into the woods, I have a responsibility to look and see what's going on. Local compartmentalizing [of management and science] is not helping." (User 28)	Moderate	N/A‡
	Harvest dead cedar	"I think we ought to log those areas [of decline] in National Parks and replant there too." (Manager 11) "I even support harvesting some of the standing dead in our Wilderness areas." (User 20)	Low	Low
	Shift or expand protections	"If there are places that have the right [conditions] that allow for healthy yellow-cedar, then it probably bears protecting some of those places…" (User 13)	Moderate	Low
	Site-specific planting	"I mean, if going into an area to help regenerate is something we can do to fix a wrong…I would say [planting] is perfectly acceptable to do in a Wilderness area." (User 10)	Low	Low
	No intervention or change in practices (emergent)	"We should let [protected areas] be, and that holds true for yellow-cedar decline." (User 13)	Moderate	Moderate
Managed lands	Assist migration (emergent)	"If we know that [yellow-cedar] is going to start dropping out in certain areas, but presumably new areas would be opened up that weren't really part of their range before, I don't see why we shouldn't promote that." (Manager 2)	Moderate	Moderate
	Enhance management collaboration (emergent)	"[Management] would probably be a lot better if the forest were managed by some sort of interagency type of setup." (User 3) "[Our managing agencies] have…an institutional wisdom from everything that's preceded, but…we have a long way to evolve before we get to a management style that will actually take care of the forests for the long-run." (Manager 5)	High	Moderate
	Harvest dead cedar	"I would apply some sort of management paradigm that values the dead as well as the living." (User 6) "If you keep [harvesting dead yellow-cedar] within a thoughtful community scale and size, then it's absolutely appropriate." (User 19)	High	High
	Experiment and monitor (emergent)	"The Tongass does have a responsibility to adapt, monitor, and adapt…" (User 29)	Moderate	High
	Limit harvesting individuals that are more likely to survive	"Harvest [instead] where [yellow-cedar] is fragile, exposed, and more likely to [die]." (User 19)	Moderate	Moderate
	Limit harvesting the species across the region (emergent)	"Definitely stop logging at a rate that is reasonable to characterize as liquidation. That means taking into account how fast it grows, how much there is, how it's distributed, and all the processes, including dieback." (User 6)	Moderate	Low
	Selectively thin (emergent)	"…yellow-cedar would do better if it weren't for competition with other species. So it would take active management to favor yellow-cedar like giving it preference when we're doing pre-commercial thinning…" (Manager 2)	Moderate	Selectively thin (emergent)
	Site-specific planting	"If we're doing active management in some places, then it makes sense to see if it'll do well [with planting] in those sites." (Manager 2) "We should have a planting program, but we also need to know the best conditions for planting." (User 9) "If they're dying, put some back." (User 27)	Moderate	Moderate
	No intervention or change in practices (emergent)	"I'm not a strong advocate of going in and doing much about [the dieback]. If we go in and manipulate something that is happening on such a massive scale, we would probably screw it up because that's our history…" (Manager 8)	Low	Low

† Emergent practices were not included in direct questions but arose from study participants.
‡ Practice that did not emerge from managers.

importance of considering resource user values in decision-making. Monitoring impacts is an important step to inform management practices (Lawler et al., 2010). The flagging, reduction of crown fullness, and dead tops observed in WCYW could help monitor the health status of yellow-cedar in protected areas for early warnings of dieback. Fischman et al. (2014) suggest that landscape-level adaptation will require protected-area managers to actively engage with managers across land ownerships and designations with objectives different than their own. Users in our study strongly supported such increased collaborations, but the moderate support among managers is a challenge.

4.2. Managing species impacted by climate change

When making decisions about future adaptation for other systems experiencing impacts, understanding the views of protected areas held by users and managers—such as viewing humans as separate from, versus a part of, "natural" areas—may help reconcile differing perspectives on adaptive strategies (Fig. 1). Individuals' views of protected areas form the foundation of perspectives on whether or not to intervene in protected areas.

The relatively low level of support we found for using unconventional practices in protected areas was consistent with the literature (Hagerman et al., 2010; Hagerman and Satterfield, 2014). “Naturalness” often guides decision-making about practices in protected areas (Keiter, 1988; Aplet and Cole, 2010; Hobbs et al., 2010), yet it is often at odds with changing ecological conditions and historical land uses. Cronon (1996) argues for moving beyond the concept of wilderness as landscapes in which humans are separate from nature, because it prevents realization of many values offered by nature. Although protected-area intervention was contentious, our findings suggest that users and managers who perceive humans to be part of nature and those who view protected-area designations as unwarranted may be more likely to consider interventions in these areas.

5. Conclusion

Analyzing fine-scale, current conditions through vegetation and temperature data, and broader-scale, future conditions through environmental risk factors, allowed us to develop system-specific metrics (e.g., stress indicators) that better connect local monitoring efforts with management practices. By integrating social and ecological data in multiple-scale analyses through our innovative methodological approach, we advanced understanding of adaptation challenges in resource management and conservation.

To apply this organizing framework as a tool for adaptive management and conservation in other systems, we suggest: (1) surveying managers to assess their views of protected areas that may influence individual support for specific adaptive practices, and (2) surveying users to explore the use values of the resource impacted by climate change where it is affected, unaffected, or may support future populations. Through such a process, collaborative decision-making may help reconcile diverse perspectives related to protected-area intervention and climate adaptation strategies for documented and predicted ecological impacts. Research in other “disturbed” landscapes suggests that, over time, residents' innovative uses of the impacted local environment may influence development of new relationships between people and place, and new values people derive from nature (Broto et al., 2010; Lukacs and Ardoin, 2014). Decision-making on when, where, and how to adapt practices in a changing climate may be improved by considering the spatial and temporal distribution of benefits people derive from an impacted resource across land designations, and the views that local managers hold of protected areas.

Acknowledgments

Financial support was provided by the George W. Wright Climate Change Fellowship (Task Agreement #P11AC90970, under Cooperative Agreement J8W07110001, US Department of Interior and the University of Washington); the Morrison Institute for Population and Resource Studies and the School of Earth, Energy, and Environmental Sciences at Stanford University; the Wilderness Society Gloria Barron Fellowship (10017-32155); the National Forest Foundation (WSC BD-001, WSC BE-002, WSC BF-002); and USDA Forest Service Pacific Northwest Research Station (Joint Venture Agreement 11-JV-11261937-083) and Forest Health Protection. The lead author was supported by an NSF Graduate Research Fellowship. Research in GLBA was authorized by the National Park Service under permits GLBA-00192 and 00161. Valuable local knowledge of the study area and assistance with remote logistics were provided by L. Sharman, P. Johnson, and G. Streveler, who also reviewed our yellow-cedar distribution mapping. We thank Kevin O'Hara for his feedback on plot data analysis and the application of our organizing framework to other systems; field assistants K. Cahill, P. Fischer, O. Miller, T. Ward, C. Radis, and G. Treinish; coding assistants C. Woolsey and R. Malczynski; and many community members throughout southeast Alaska whose support made this study possible. Adventurers and Scientists for Conservation reclaimed sensors in WCYW with support from S. Harris and the Sitka Conservation Society. We thank Captain Z. Stenson and his volunteers who reclaimed temperature sensors in GLBA. F. Biles, USDA Forest Service geographer at the Pacific Northwest Research Station in Juneau, Alaska, developed the topographic wetness index. We are grateful for the interviewees who generously shared their perspectives, time, and hospitality. K. Cahill contributed tree drawing to Fig. 1. Comments from A. Cravens and F. Moore improved this manuscript, and W. Hoover provided copyediting assistance.

Appendices. Supplementary data

Supplementary materials on the background of yellow-cedar decline and values of the species (Appendix A), methods (Appendix B), additional figures from results on population structure and thermal regimes (Appendix C), and modeling limitations (Appendix D) are available online. Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2015.09.018.

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