National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Setting the Stage for Climate Change Scenario Planning

Whitebark Pine and American Pika in the Sierra Nevada, Klamath, and Upper Columbia Basin Inventory and Monitoring Networks

Natural Resource Report NPS/KLMN/NRR—2019/1960

ON THIS PAGE
Photograph of sheer ridges and extensive scree fields of the eastern Sierra Nevada, CA.
Photograph courtesy of J. KELLERMANN

ON THE COVER
Photograph of whitebark pine on the rim of Crater Lake National Park with smoke from the National Creek Fire visible.
Photograph courtesy of J. KELLERMANN

Setting the Stage for Climate Change Scenario Planning

Whitebark Pine and American Pika in the Sierra Nevada, Klamath, and Upper Columbia Basin Inventory and Monitoring Networks

Natural Resource Report NPS/KLMN/NRR—2019/1960

Jherime L. Kellermann[1, 2], Thomas J. Rodhouse[3], Jonathan C. B. Nesmith[4], and Alice Chung-MacCoubrey[5]

[1]Oregon Institute of Technology
3201 Campus Dr.
Klamath Falls, OR 97601

[2]National Park Service
Crater Lake National Park
Crater Lake, OR 97604

[3]National Park Service
Upper Columbia Basin Network
Bend, OR 97702

[4]National Park Service
Sierra Nevada Network
Three Rivers, CA 93271

[5]National Park Service
Klamath Network
Ashland, Oregon 97520

August 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on well-established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Klamath Inventory & Monitoring Network and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Kellermann, J. L., T. J. Rodhouse, J. C. B. Nesmith, and A. Chung-MacCoubrey. 2019. Setting the stage for climate change scenario planning: Whitebark pine and American pika in the Sierra Nevada, Klamath, and Upper Columbia Basin Inventory and Monitoring Networks. Natural Resource Report NPS/KLMN/NRR—2019/1960. National Park Service, Fort Collins, Colorado.

NPS 940/156549, August 2019

Contents

Contents (continued)

Figures

Tables

Appendices

Executive Summary

Climate models project a range of potential future conditions in our national parks and protected areas, which necessitates strategic management plans that acknowledge significant uncertainty. Likewise, the ecological impacts of changing policy and political environments, social perspectives, and technological capacities across biogeographic regions are currently highly uncertain. Scenario planning is a widely used tool that integrates current knowledge and conditions with modeled projections and their associated uncertainty. By identifying important drivers and indicators of change, knowledge gaps, idiosyncrasies of place, and possible conflicts or resistance points, we can explore uncertainties, prioritize actions and resources, optimize our preparedness, limit future risk in our management strategies, and increase our potential to respond to change with greater efficiency, speed and confidence. Effective scenario planning requires substantial initial preparation. It requires building a core project team, identifying the strategic challenges and goals, compiling a baseline of the best available information on relevant science, contemporary socio-political perspectives, and technological challenges, and identifying gaps and uncertainties in this information. This project initiated the Orientation and Exploration phases of scenario planning (NPS 2013) to build a foundation for future scenario development actions across three National Park Service (NPS) Inventory and Monitoring Networks: Klamath, Sierra Nevada, and Upper Columbia Basin.

This report is intended to inform resource managers, planners, and scientists considering new scenario planning efforts and/or those who are concerned with the conservation and management of natural resources within or shared with our three network regions. The available guides and handbooks for scenario planning lack specific experiential details on “getting started.” Therefore, we present both 1) our recommendations and lessons learned from the process of initiating scenario planning for a large, diverse biogeographic region, and 2) the results of our scenario planning efforts to date.

Our initial intent was to conduct scenario planning for montane and high elevation ecosystems. However, we were advised by the NPS Climate Change Response Program to minimize the inherent complexity in an ecosystem approach. Thus, we elected to focus on two species of conservation concern, whitebark pine (*Pinus albicaulis*) and American pika (*Ochotona princeps*). These species occur in all regions, have significant range overlap, have established monitoring protocols, and are relatively well studied at multiple scales. Furthermore, during the last glacial period, they both had high range overlap and experienced range expansion, greater connectivity and gene flow, followed by range retraction and fragmentation since. Additionally, since they are phylogenetically disparate, contrasting these species provides unique insight into the drivers of change in montane and high elevation ecosystems as well as a diversity of low elevation habitats where pikas occur.

In order to review the current state of knowledge and identify key drivers of change and their associated uncertainties, we invited a group of experts from agency and academic backgrounds to two separate workshops—one for each of our focal species. In addition to the valuable information we learned from our invited experts we also learned several important organizational lessons to this stage of scenario planning relevant to a small project with limited time and funding: 1) keep it small and focused and 2) invite a professional scenario planner, 3) provide materials in advance, 4) capture everything, and 5) eat well!

Although we gathered valuable insights informing our goals through both meetings, due to our extremely limited time and resources, we found that these one-day workshops were more effective with the small team of about 5 to 6 people who are committed to the success of the project versus a larger group of over 12 that may be participating for a variety of other reasons. Our second, smaller workshop also benefited greatly from inclusion of a professional scenario planner with extensive experience and knowledge of natural resources and agency management who could help guide and focus our team (Appendix 1). Prior to the workshop, organizers should provide attendees with clear goals and outcomes, an organized framework or agenda that is flexible enough to allow for opportunistic and synergistic discussion that could result in novel insights, and background information – especially regarding the scenario planning process. During the workshop, designate note takers and/or make audio recordings to capture everyone's comments and contributions. Use large wipeboards to capture and compile thoughts as the conversation evolves so that everyone can see the trajectory of the group's thinking. Be sure to take photographs of the wipeboards before they are erased. Lastly, although it seems mundane, we recommend arranging for an onsite lunch to prevent disrupting the continuity and flow of conversations, to build further group comradery, and to maximize time use. If budget allows, provide a catered "working lunch," or ask attendees to bring their own sack lunch.

Following the workshops, the next challenge was to analyze, summarize, and communicate results. Closing workshops with clearly defined next steps and action items can help. If focal taxa are core to the project, expect that the amount of published research and natural history knowledge available will vary greatly. Significant knowledge gaps regarding fundamental aspects of physiology, behavior, or ecology may be one of the biggest sources of uncertainty for some species, therefore identified knowledge gaps may be filled through further literature searches or interviews of other experts, while others may require novel research or monitoring which will then need to be prioritized in order or urgency and necessity.

Documented and projected climate change varies across network regions and constituent parks with varying levels of uncertainty. Most parks have experienced significant warming over the past century, a trend that is projected to continue. While future precipitation is far less certain, dry regions will likely experience continued drought and montane areas will continue to have decreasing snowpack and earlier snowmelt dates. This will likely have important but highly uncertain impacts on species phenology, phenological synchronies, and growing season length.

Pikas and whitebark pines show significant biogeographic variation across their range, particularly pikas which persist in an extreme range of habitats and landscapes from the subalpine Sierra Nevada to lava lands of the high desert to the cliffs of the Columbia Gorge. Therefore, management strategies will often need to be tailored to the "idiosyncrasies of place" and its local conditions, concerns, and resources. Critical factors driving whitebark pine population dynamics are the exotic fungal pathogen, white pine blister rust, and the native mountain pine beetle, as well as fire. All of these factors will likely experience their own significant climate-driven and highly uncertain changes. Key factors for pikas include connectivity and isolation of habitat patches and metapopulations, phylogenetic constraints, such as dispersal limitations, and the interaction of biogeography, geologic habitat structure, vegetation, and microclimates. A major challenge for research and its management applications for both species is the diversity of analytical models used, how they are related, their levels of uncertainty, and how differences in results may be model-dependent.

Identifying genetic connectivity among populations and local adaptation of both species will be important for assessing future management options and their associated risks, such as increasing functional connectivity versus assisted migration. This presents technological, philosophical, and managerial challenges, such as identifying adaptive genetic markers for rust-resistance in whitebark pine; monitoring physiological vital signs and survival of individual pika; knowing when, how, where, and which plants or animals should be moved; and how to fund long-term management strategies within short-term funding cycles. Both species will benefit from identifying near-term, low-risk management actions that will increase functional connectivity and maintain genetic diversity based on local population requirements.

Conceptually one of the most important perspectives that emerged from this work was that despite the significant climatic and ecological change these species have experienced since the last glacial maximum, they have and continue to persist, perhaps through core refugia and local adaptation to diverse habitats. Therefore, we suggest that science communication messages consider a shift in the representation of these iconic species from beacons of peril to emblems of persistence to encourage an optimistic rather than fatalistic perspective. While we urgently need to better understand the potential impacts of current anthropogenic and environmental change, there may be reasons for optimism.

Consider a shift in the representation of these iconic species from beacons of peril to emblems of persistence.

Significant portions of both species’ ranges lie within wilderness areas. Agency interpretation of the Wilderness Act, as well as public ideals of wilderness ethics, requires significant forethought. These considerations must be addressed prior to management actions to limit conflicts and delays and garner broad support and buy-in. Conservation of both species will benefit from outreach to and education of the public and resource managers

Our current efforts will

- serve as a platform for the creation and application of scenarios,
- develop a structure for better communication and information sharing at a regional scale,
- showcase multi-network Inventory and Monitoring Program projects,
- pull together parallel efforts of regional partners, and
- work towards synthesizing current information, perspectives, and challenges.

Acknowledgments

Thanks to all of our colleagues and partner agencies and organizations that participated in and contributed to this project, particularly Connie Millar, Matthew Shinderman, Sean Smith, Jennifer Beck, Mac Brock, Diana Tomback, Bob Keane, Doni, Schwalm, and Holly Hartman.

Introduction

Global surface temperature has been increasing over the past century, particularly over the past three decades (IPCC 2014). However, change has not been homogeneous; mountainous and high elevation areas are experiencing greater rates of change than many surrounding lower elevation regions (Pepin et al. 2015). Rising temperatures have led to loss of glacial ice and declining snow pack, which are altering fundamental hydrological and ecological processes (Rango and van Katwijk 1990; Barry and McDonald 2012; Nolin 2012). These changes raise significant concern for national parks and protected areas that encompass montane and high elevation ecosystems (Moritz et al. 2008; Muhlfeld et al. 2011; Rowe et al. 2015). Many parks are already at the extreme warm end of their historic range of variation for climate variables such as mean annual temperature and minimum temperature of the coldest month (Monahan and Fisichelli 2014). Management agencies are mandated to incorporate climate change into action plans (Burns et al. 2003), creating significant demands for ecological data at large temporal and spatial scales to make science-based decisions that acknowledge changing conditions and novel futures (Baron et al. 2009).

Climate change impacts are expected to continue and increase in many regions, necessitating new paradigms in resource management. Executive Order 13653, stated that “adaptive learning, in which experiences serve as opportunities to inform and adjust future actions” succinctly describes the need for scenario planning and adaptive management. We commonly hear the term “climate change adaptation,” which involves the identification, development, and application of management actions in response to climate change that take advantage of beneficial opportunities and/or minimize negative impacts to resources (National Resource Council 2010). Climate change adaptation requires that scientists and managers learn from the past while “looking forward” to anticipate plausible but uncertain conditions, and to expect surprises. Therefore, managers must revisit their goals in light of the “desired conditions” that are frequently described in the context of historical conditions, but that may no longer be tenable under future novel climate and environmental conditions.

Understanding and adapting to climate change is extremely challenging, in large part due to high levels of uncertainty surrounding climate change projections at scales relevant to resource managers. Resource managers and policy makers can be overwhelmed by the complexity and uncertainty in climate change projections and often lack applicable knowledge of local effects and readily apparent ways to respond (Lawler et al. 2008). Furthermore, climate change is only one of many factors that drive environmental change, including government and agency policy, management strategies and perspectives, social perspectives, and technological advances and challenges.

National park management has traditionally followed the Precautionary Principle (PP) which is broadly defined and interpreted differently by various groups and disciplines. In application of the PP to the environmental sciences where the intention is ultimately to affect policy and decision making the PP has four central components: 1) taking action in light of uncertainties, 2) placing the burden of proof to the proponents of an activity, 3) identifying alternatives to harmful actions, and 4) increasing public participation in the decision making process, especially from vulnerable populations (Kriebel et al., 2001; Morello-Frosch et al., 2002). Particularly relevant to a discussion of natural resource management planning and actions in the face of climate change-related uncertainties is number 2. In the absence of scientific consensus regarding fundamental components of a problem, proponents of an action must show that the action is not harmful, rather than asking opponents to prove that it is, placing the burden of proof on proponents. The focus is therefore on potential actions, and inaction is not *necessarily* subjected to such analysis, either because it is already the status quo or because inaction may be assumed to be safer or cheaper in the short term. Strict adherence to the PP would advise that no action be taken until the deciding party could attain high levels of certainty that the proposed actions would cause no harm to the managed resources. Although the PP is rarely followed to this extreme, it can still pose challenges for those making management decisions in the face of significant uncertainties. One important source of difficulty stems from our reliance on predictions and projections of future conditions and their levels of uncertainty and the potential impacts of, and interactions with management actions. These issues are plagued by uncertainties, and the more complex the system (e.g., climate and ecosystems) or distant the projection (e.g., decades to centuries), the greater the uncertainty. Second is the problem that waiting for “more information” or “better projections” while doing nothing may cause more harm than taking immediate action with the best information available. Furthermore, risk aversion and “disdain for uncertainty” is an oversimplified view that does not integrate the value or utility of an action’s outcomes with the probability of occurrence (Falcy 2016). The International Panel on Climate Change recognizes this problem, stating that, "With the precautionary principle, uncertainty about the damage to be incurred does not serve as an argument to delay action. In the face of great uncertainty, a precautionary approach might even result in a more stringent…adaptational response" (IPCC 2014). Therefore, if we incorporate acknowledgment of uncertainty into the PP, we should develop management strategies that integrate uncertainties and consider possible future conditions. Integrating the PP with uncertainty in key conservation metrics typically used to assess the need for management actions, such as population trend, could help integrate explicit statements of statistical uncertainty with risk and loss aversion thus create greater transparency in decision making (Falcy 2016).

Scenario planning

One climate change adaptation tool that may help incorporate uncertainty into management strategies for protected area resource managers is scenario planning. Scenario planning integrates scientific knowledge in the context of environmental, social, political, economic, and technical factors to explore and describe a range of plausible futures. This enables managers to consider how to define and meet their desired conditions under changing circumstances with greater efficiency and confidence (Weeks et al. 2011). Under some scenarios, it may be possible to develop effective conservation and management strategies using familiar tools, whereas in other scenarios, novel ecological conditions may preclude “business as usual” and require paradigm shifts in protected-area management.

In order to provide a scientific foundation for scenario development, scientists supply data-driven information on climate and environmental drivers, future climate and environmental trends, ecological impacts, and the associated degree of uncertainty.

Conducting effective scenario planning requires substantial preparation "up-front." It requires building a team of diverse stakeholders, identifying strategic challenges and goals, identifying uncertainties, and compiling the best available scientific information. Scenario planning projects that addressing greater complexity—ecosystems rather than individual species, large landscapes, multiple stakeholders, or long time periods—will require greater preparation and resources.

Multinetwork partnership

This project was conceived, funded and implemented as a partnership among the Klamath, Sierra Nevada, and Upper Columbia Basin National Park Service Inventory and Monitoring (I&M) Networks (Figure 1), the Crater Lake National Park Science and Learning Center, and the Oregon Institute of Technology. The individual national park units in each Network are listed in Appendix 2.

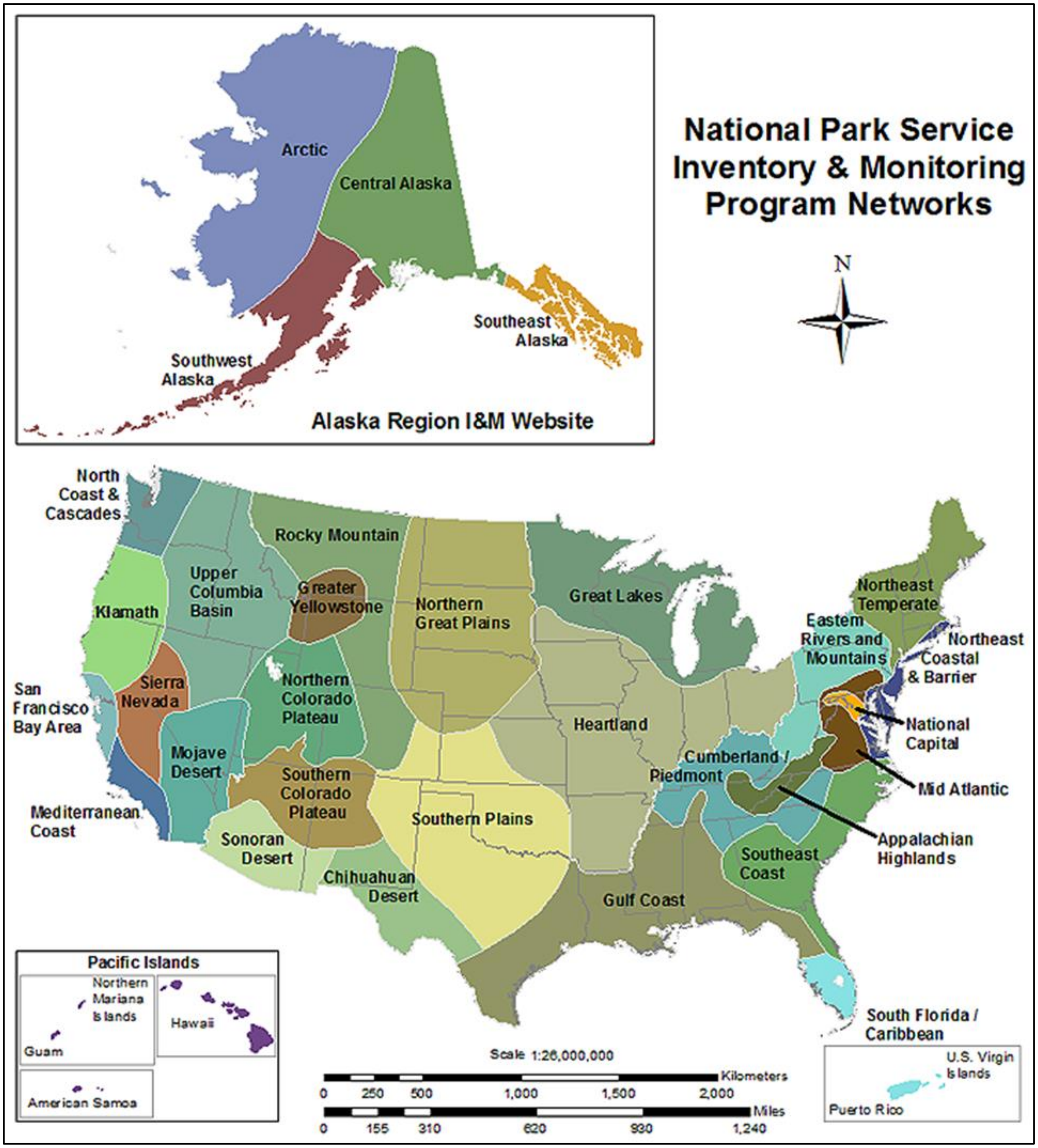

Figure 1. National Park Service Inventory and Monitoring Networks.

By bringing together a regional team, this project will leverage existing research and monitoring information to apply scientific knowledge to management actions and decision making.

Focal species

Whitebark pine (Pinus albicaulis)

Whitebark pine (WBP) is a dominant late successional species of upper subalpine and treeline communities in mountain regions of western North America. As a foundation species (Dayton 1972) WBP plays critical functional roles, including soil stabilization, modulation of runoff and stream flow (Farnes 1990), community development after disturbance, and nursery and tree island initiation. WBP also provides habitat and is a vital food resource to a wide range of wildlife, including birds, small mammals, large ungulates, and carnivores, such as black and grizzly bears. WBP has a complex mutualistic symbiosis with the Clark's Nutcracker (*Nucifraga columbiana*), which disperses and sows WBP seeds, driving the spatial and genetic population dynamics of WBP (Tomback 1982; Linhart and Tomback 1985; Richardson, Klopfenstein, and Brunsfeld 2002). The decline and loss of foundation species can have broad cascading effects throughout ecosystems (Ellison et al. 2005), heightening the concern over population declines of WBP in the northern portions of its range.

Foundation species:
A species with a role central to the maintenance of a community, stabilizing fundamental ecosystem functions and defining community structure to an extent disproportionate to their abundance or biomass. Although they may occur at any trophic level, in forested ecosystems they are often tree species.

WBP is a species of "stone pine," which has cones and wingless seeds adapted to dispersal by birds. WBP is (variably) related to other five-needle pines in western North America, including sugar pine (*Pinus lambertiana*), limber pine (*Pinus flexilis*), foxtail pine (*Pinus balfouriana*), and western white pine (*Pinus monticola*). WBP is shade-intolerant, slow growing, and long-lived—capable of living more than 1,000 years (Perkins and Swetnam 1996) in the harsh environments near and along treeline.

WBP has the largest and most northern distribution of any five-needle pine in North America. The distribution of WBP can be broadly split into a pacific western section that includes the Sierra Nevada, Klamath, Cascade, and Olympic mountain ranges of California, Oregon, Washington, and British Columbia, and an eastern section that includes the interior ranges of the Rocky Mountains and the Greater Yellowstone Ecosystem. The Sierra Nevada and Cascade mountain ranges generally lack the large subalpine "seral whitebark pine" systems more common in the eastern (Rocky Mountain) sections of the WBP's range. The Pacific Western region includes "climax whitebark" communities in upper subalpine habitats and at tree line where in the Sierra if not in the OR/WA Cascades, WBP is the dominant if not only species in the upper subalpine and treeline zones (Millar, personal communication). In the Pacific regions, WBP dominate relatively harsh dry, cold, and windy slopes, sometimes creating classic krummholz communities of truncated growth forms and elfin forests. WBP also regularly occurs in tree and stand clusters, islands or ribbons in the alpine-treeline ecotone (Arno and Hoff 1989).

In July 2011, the U.S. Fish and Wildlife Service listed WBP as a candidate species for listing under the Endangered Species Act, with annual review (U.S. Fish and Wildlife Service 2011). In December

2015, the priority for WBP was lowered based on recent subsidence of the mountain pine beetle epidemic (U.S. Fish and Wildlife Service 2015).

American pika (Ochotona princeps)

The American pika is one of only two species of the genus *Ochotona* that occur in North America, the other being *Ochotona collaris*, which extends throughout western Canada and Alaska. Pikas form their own family, *Ochotonidae,* within the Lagomorph order, which include rabbits and hares. Numerous other *Ochotona* species are distributed across northern Asia and were likely the colonization source for the two American pikas species during the Pliocene (Yu et al. 2000). Pikas are patchily distributed throughout mountainous regions of western North America across broad elevational and latitudinal gradients (Smith and Weston 1990). While typically associated with upper elevation montane, subalpine, and alpine habitats in national parks such as Yosemite and Crater Lake, pika populations also occur in low elevation sites, including Craters of the Moon, Lava Beds, Newberry Crater National Monuments, and the Columbia River Gorge, with elevations ranging from about 4,000 m down to only 121 m (Simpson 2009; Rodhouse et al. 2010; Shinderman 2015; Ray et al. 2016), and many other low-elevation sites outside of park units in the Pacific states.

Pikas are extremely temperature sensitive. They utilize microenvironments of talus and boulder fields, which have unique circulation systems that maintain cool internal temperatures (Millar et al. 2014, Millar, Westfall, Evenden, et al. 2015) to avoid summer heat (Smith 1980) and rely on the insulation of snowpack for protection from winter cold (Millar and Westfall 2010; Millar, Westfall, Delany, et al. 2015). Their thermal sensitivity makes pikas highly vulnerable to temperature and snowpack variability and extremes associated with climate change and thus ideal indicators of ecological response to environmental change (Hafner 1993). Pikas have experienced population loss in some marginal environments over the past century, primarily in the Great Basin, (Galbreath et al. 2009; Beever et al. 2014). However, despite local extirpations, pika populations appear to be thriving across their geographic and elevational range (Millar and Westfall 2010; Rowe et al. 2015), including in the Great Basin where pikas may be able to tolerate a much broader range of habitat conditions than we previously understood or assumed (Millar et al. 2018; Smith and Millar 2018). So, although there is extensive work supporting the general narrative of pika decline and range contraction, there is also a growing body of literature suggesting that pika demonstrate uncanny ability to moderate temperature influences via behavioral adaptation and habitat use. Some populations probably are threatened by continued warming, but evidence suggests other populations may persist (Jeffress et al. 2013; Millar et al. 2016; Smith and Millar 2018). In fact, there is increasing evidence that pika have occupied low elevation habitats like Newberry Crater, Lava Beds, and the Columbia River Canyon continuously over extensive periods of environmental and climate change (Collins and Bauman 2012; Ray and Beever 2007; Rodhouse et al. 2010; Shinderman 2015; Simpson 2009). Ultimately, it is critical to remember that our understanding of American pika is growing and changing and that the narrative focusing on “extinction threat” should be balanced with one of “persistence in the face of change” and recognize that there is uncertainty about whether universal, species-level impacts will occur (See the section on Peril vs. persistence).

Although pikas spend parts of their days during the winter months below the surface, insulated by seasonal snowpack, they do not hibernate or undergo torpor. Pikas collect "hay" composed of a range of forbs, grasses, moss, and other trees and shrubs during the summer months and store it in piles under rocks in the talus to survive the winter (Dearing 1995). Therefore, environmental impacts on plants that affect the phenology, availability, abundance, or nutritional quality of summer and winter forage could have significant impacts on fitness and survival. However, despite the value of snow as insulation, and its potential impact on habitat pikas were able to survive winters of extreme low snow, and in fact maintain high population densities in the Sierra Nevada (Smith and Millar 2018) through mechanisms we do not currently understand fully.

American pikas have been considered for protection under the California State and Federal Endangered Species Acts. In California, a petition was submitted by the Center for Biological Diversity in 2007 to list the American pika as threatened pursuant to the California ESA or alternately to list each of the then recognized five subspecies of pikas occurring in California as variously either endangered or threatened. After a thorough review utilizing the best science available the U. S. Fish and Wildlife Service (2010):

> "acknowledged that the American pika is potentially vulnerable to the impacts of climate change in portions of its range, but that the best available scientific information indicated that the species will be able to survive despite higher temperatures and that there is enough suitable high elevation habitat to prevent the species from becoming threatened or endangered. (Mastrup 2013 http://www.fgc.ca.gov/regulations/2013/)"

In April 2016, a New York high school student filed a petition for listing of the American pika (USFWS 2016). Based on the 2010 12-month findings the Fish and Wildlife Service decided that neither the species nor its subspecies warranted listing because there were not "threats of sufficient imminence, intensity, or magnitude as to cause substantial losses of population distribution or viability" (FWS-R6-ES-2016-0091-0002). The reasoning for this decision followed that

> "analysis of climate change information…found that American pika can tolerate a wider range of temperatures and precipitation than previously thought…can demonstrate flexibility and move to cooler habitat when temperatures increase (and)… an increase in summer surface temperatures due to climate change is not a significant threat to the entire species (FWS-R6-ES-2016-0091-0002)."

All federal documents on ESA petitions and decisions can be found at regulations.gov.

California State documents on American pika are available at California Department of Fish and Wildlife.

Project purpose, strategic challenge, and focal question

A clear project purpose, strategic challenge, and focal question(s), as well as desired outcomes are critical to the scenario planning process (Rose and Star 2013).

Project purpose

Identify and explore drivers of change and their associated uncertainty for whitebark pine (WBP) and American pika population dynamics and persistence across protected areas of the Sierra Nevada, Klamath, and Upper Columbia Basin National Park Service I&M Networks to inform future scenario development and management options and decisions.

Strategic challenge

Under some climate scenarios, it might be possible to develop effective conservation and management strategies using familiar tools. In other scenarios, however, wholly novel conditions may preclude “business as usual” and require large paradigm shifts in approaches to protected-area management and immediate action. For example, long-term planning for increased resiliency and connectivity and active management within designated wilderness are already significant challenges facing WBP and American pika management.

Focal questions

What will be the key drivers of change in montane and high elevation protected areas of the Klamath, Sierra Nevada, and Upper Columbia Basin I&M Network regions over the next 20–30 years? How can managers incorporate uncertainty into their management plans to conserve key species? What drivers and uncertainties are shared across regions and which are unique to particular parks or regions?

Project and report goals

The goals of this project were to a) initiate climate change scenario planning, as illustrated by our project purpose, strategic challenge and focal questions above, b) provide experiential insight into our process beyond the “how to” guides available for others wishing to implement this climate adaptation tool, and c) provide a synthesis of key results from our activities that will inform future scenario planning activities and implementation of recommended actions. This report contains two main sections: 1) Methods: how we got started, how we progressed, “lessons learned” from our experience of initiating climate change scenario planning, and recommendations for others attempting the same, and 2) Results: a synthesis of key drivers of change for our focal species and implications for scenario development that emerged from workshops.

Methods

There are several excellent “how to guides” or “handbooks” available for scenario planning (Rose and Star 2013; Rowland et al. 2014). At the root of these documents are conceptual diagrams and flow charts that outline methods, procedures, and schedules for doing scenario planning. Despite the proposed scenario planning recipes in these documents, they also insist that there is no “one way” to do scenario planning. The methods described should only be used as guidelines, and that we should take a flexible approach to the scenario planning process so that it may best adapt to individual project needs. However, it is somewhat unclear how to get started and these documents lack nitty gritty details for enacting a scenario planning venture. Here we report on our experience initiating a scenario planning project for a large biogeographical region and make recommendations for those considering undertaking a scenario planning initiative.

Our overall process follows:

1. Build a team of experts for each species.
2. Invite them to an organized workshop to discuss drivers and factors of change in population and species persistence, knowledge gaps, and other species conservation and management concerns.
3. Compile available literature to build working bibliographies for future efforts, review this literature to further explore the drivers and uncertainties identified in workshops, and synthesize this information in reports.

Workshops

Whitebark pine workshop

We timed our whitebark pine (WBP) workshop held on September 16, 2015, to coincide with the Whitebark Pine Ecosystem Foundation annual meeting hosted at Southern Oregon University in Ashland, Oregon, as this is where the Klamath I&M Network office is located. We took advantage of the diversity of experts already traveling to the Klamath region for the conference (Figure 2).

Figure 2. A breakout group discusses key drivers of whitebark pine population dynamics during our workshop at Southern Oregon University in Ashland, Oregon, in September 2015.

We invited a fairly extensive team of experts with detailed understanding of the current state of knowledge for WBP and who could speak to our level of certainty regarding current knowledge of the species' biology and ecology, regional climate and environmental factors, and regional to national sociopolitical factors. We reached out to experts from agencies and academic institutions within each of the three I&M Network regions. We also invited individuals from the Rocky Mountain region in order to help explore and highlight differences between the Pacific (western) and Intermountain (eastern) portions of the species range. Of the 20 participants we initially invited, 13 were able to attend. A complete list of workshop participants and their affiliations is provided in Appendix 3.

We created a workshop agenda prior to the meeting and provided this along with a recommended reading list for background on scenario planning (Appendix 4). After introductory talks to review the status of WBP and some background on scenario planning, we asked workshop participants as a group to review and revise where necessary the project purpose, strategic challenge, and focal question. After lunch, we created two breakout groups charged with generating a list of drivers affecting WBP populations, their effective management and conservation, and the associated uncertainty. We then came back together at the end of the day to briefly share and discuss each group's products.

American pika workshop

On April 1–2, 2016, we held a workshop on American pika in Bend, Oregon (Figure 3). We assembled a much smaller team of experts, all of whom were actively researching pikas within our study regions (Appendix 1). We invited researchers that work with pikas within focal regions, including the Sierra Nevada, Crater Lake National Park, Lava Beds National Monument, and Newberry Crater National Volcanic Monument. We also included a consultant highly experienced in climate change scenario planning for natural resources, Dr. Holly Hartmann, to help facilitate our discussion and provide insight and guidance on how our current efforts would be most useful for informing future scenario formation. Our goals were the same as for the WBP workshop: to identify and discuss current and future factors influencing pika populations, uncertainties, and challenges to effective conservation and management actions (Appendix 5).

Figure 3. Our team (and family members) look for signs of pikas during a field trip to the "Lava Lands" region south of Bend, Oregon, following our climate change scenario planning workshop in April 2016.

Recommendations for initiating scenario planning

Here we provide several recommendations based on our experience thus far with the process of initiating scenario planning, especially regarding project focus, workshops, and follow up.

Start simple

During our initial conversations, we identified a need for assessment and synthesis of drivers of change in montane and high elevation ecosystems and how these may be better addressed by monitoring and management plans and actions. Scenario planning can be a complicated and intimidating process. Recommendations from the National Park Service Climate Change Response Program (Leigh Welling, personal communication) were to start at a fairly narrow ecological scale, especially considering the extremely large spatial scale of our project. Therefore, rather than an ecosystem level approach (montane, subalpine), we opted to focus at the species level. We selected our two focal species, whitebark pine and American pika because

- they have robust past and ongoing research and monitoring efforts within our I&M Networks, often using shared protocols,
- they are of range wide conservation interest,
- they are not responding to environmental change homogeneously throughout their range (Galbreath et al. 2009; Jeffress et al. 2013),
- and they are phylogenetically disparate species that minimally interact, representing distinct components of the ecosystems they inhabit.

Furthermore, these two species

- have high range overlap (Figure 4),
- had range expansion, greater connectivity and gene flow during the last glacial period (Eckert et al. 2008; Galbreath et al. 2009; Hafner 1994),

- have had range retraction and fragmentation since the last glacial period (Aitken et al. 2008; Beever et al. 2011; Clason et al. 2014; Smith 1980; Wilkening et al. 2011), and
- likely have critical refugia within our regions (Millar and Westfall 2010; Mitton et al. 2000; Rodhouse et al. 2010).

Figure 4. Distributional range map of whitebark pine (Little 1971) and American pika (IUCN 2016) in the United States and Canada.

Keep teams small

After we identified our focal species, we built teams of experts who have knowledge of and experience working with focal taxa. We invited them to one of two workshops—one for each focal species. In September 2015, the Whitebark Pine Ecosystem Foundation hosted its annual meeting at Southern Oregon University in Ashland, Oregon. We decided to host our workshop in conjunction with the meeting to facilitate attendance by a wider group of experts, including scientists from the Rocky Mountain region (Appendix 3), resulting in a diverse team of 13. This included national park resource managers and academic and agency researchers.

There were benefits and drawbacks to both approaches. The larger WBP group provided a rich diversity of perspectives, knowledge bases, and insights. However, we had only scheduled for five hours plus a 1-hour lunch break (Appendix 4). Thus, it was challenging to 1) manage our limited time, 2) obtain input from all participants, 3) explore all valuable avenues of discussion, 4) avoid spending too much time on any one discussion point or idea, and 5) develop consensus and directive for next steps. If planning a large workshop, at least two days of 5–8 hours each should be planned to facilitate complete discussions, allow all team members to provide input, and synthesize the experience. We had extremely limited time and budget, making only a one day meeting feasible for both workshops.

Inherent interest

To maximize productivity, efficiency, and longevity of the project, invite people who will participate due to their interest in the project's goals and its inherent success rather than out of convenience, to further a personal, professional, or philosophical agenda, access potential funding, or get a publication. It is also beneficial to include team members that have an inherent interest in working with each other. Comradery can greatly facilitate workshop discussions, making the event fun and exciting, and facilitate continued participation following the workshop.

Be clear

Prior to the workshop, organizers should provide attendees with clear goals and outcomes, an organized framework or agenda that is flexible enough to allow for opportunistic and synergistic discussion that could result in novel insights, and background information—especially regarding the scenario planning process. Make sure people understand what is expected of them during and after the workshop. Workshop organizers should broadly distribute reading and discussion materials several weeks before the meeting so that attendees can know in advance how to prepare and can hit the ground running. Reading through scenario planning guides such as those produced by the National Park Service (Rose and Star 2013) and the U.S. Fish and Wildlife Service (Rowland et al. 2014), as well as reports from other projects is helpful for preparing participants.

Record everything

During the workshop, have designated note takers and/or audio recordings to capture everyone's comments and contributions. Use large wipeboards to capture and compile thoughts as the conversation evolves so that everyone can see the trajectory of the group's thinking. Make sure to take photographs of the wipeboards before they are erased.

Food

Although it seems mundane, we recommend providing a catered “working lunch” for attendees in order to prevent disrupting the continuity and flow of conversations and to maximize time use. Also, eating together helps build further group comradery, which can generate new and productive avenues of conversation. As Virginia Woolf wrote, “One cannot think well…if one has not dined well.”

That was the easy part

Following the workshops, the next challenge is in analyzing, summarizing, and communicating the results. Closing workshops with clearly defined next steps and action items can help, even if these steps do not involve further participation by the workshop members.

If the project has focal taxa, expect that the amount of published research and natural history knowledge available about the taxa may vary greatly. Significant knowledge gaps regarding fundamental aspects of physiology, behavior, or ecology may be one of the biggest sources of uncertainty for some species. In our post-workshop research, we found a far greater wealth and diversity of published research on WBP than on American pika. For example, a quick search of Google Scholar for each of our focal species yields over 7,000 results for “whitebark pine” and less than 2,000 for “American pika,” In contrast, “gray wolf” yields over 14,500, and “drosophila melanogaster” delivers over 550,000!

Lastly, another challenge is accurately and concisely summarizing and communicating the wide-ranging, intricately complex, and somewhat rambling or convoluted results of workshop discussions. During both of our workshops, we generated complicated conceptual diagrams depicting the relative connections of all of the drivers of change we discussed (**Figure**). While this was extremely useful in facilitating, building, and advancing our discussion, it can be difficult to translate this multidimensional wealth of thoughts into digestible units that inform future scenario planning efforts. This report is one of our attempts at doing just that.

Figure 5. Conceptual model that emerged from the American pika climate change scenario planning workshop at Oregon State University – Cascades, in April 2016.

Sending out a follow-up questionnaire may help to gather more ideas and thoughts that participants had either during or after the workshop that were not otherwise incorporated during the meeting.

Results

Our teams identified, visualized, and explored a wide range of drivers that impact whitebark pine (WBP) and American pika populations and their management and conservation (Figure 6). These drivers are summarized in Table 1 and Table 2. We classified these drivers into six to seven broad categories, which included:

- Climate
- Geological
- Biological
- Ecological
- Technological
- Political
- Social

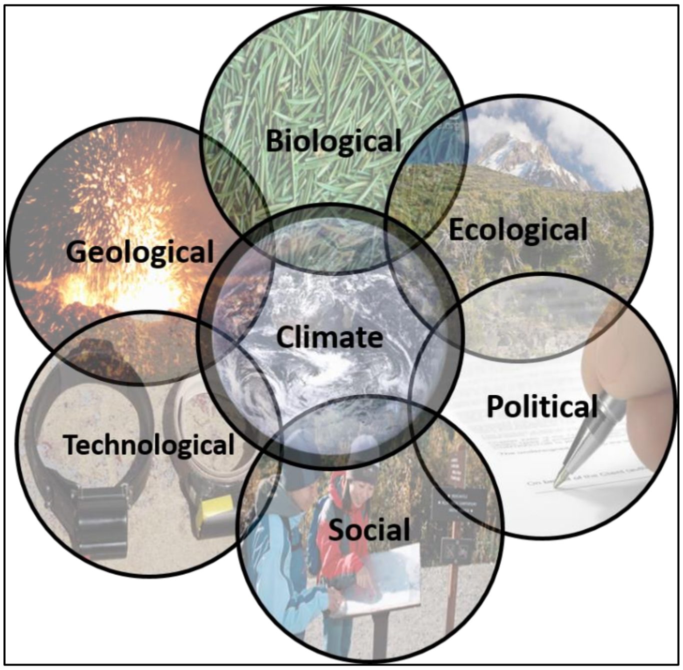

Figure 6. The broad overlapping categories of drivers of change in whitebark pine and American pika populations.

There is significant overlap and interaction among the drivers comprising these categories. Many drivers are important to understanding change in both WBP and American pika populations, whereas some are species-specific. Likewise, the conversations on each species lead to some insights on the other. Below we discuss the individual drivers by category, highlighting similarities and differences between WBP and American pika.

Table 1. Key drivers of whitebark pine population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in September 2015.

Category	**Drivers and factors**
Climate	Temperature is expected to show a continued warming trend but precipitation is highly uncertain locally and across regions Snowpack and snowmelt timing are highly variable and uncertain
Geological	Population specific soil requirements are uncertain Impacts of drought and reduced snowpack on hydrology are uncertain
Biological	Potential impacts of temperature and precipitation on cone production, seed germination, mortality, and seedling growth and development are highly uncertain Local and regional adaptation and population regulation relative to local climate and pathogens is uncertain Biogeographic variation in genetic blister rust resistance in whitebark pine is uncertain Potential adaptation and genetic structure in pathogens is uncertain
Ecological	The relative contribution of top 2 key stressors, white pine blister rust, mountain pine beetle, to population dynamics across regions is uncertain Climate impacts on community interactions, especially pathogen host availability and encroachment of shifting tree communities, is uncertain Impacts of tree mortality and low cone production on Clark's Nutcracker populations and WBP dispersal and population dynamics are uncertain Potential for new or novel pathogen outbreaks in Clark's Nutcrackers is highly uncertain Introduction of new WBP pathogens highly uncertain Future fire regimes and mosaics are highly dependent on temperature, precipitation, snowpack, and snowmelt are extremely uncertain Mycorrhizal community responses to climate changes (temperature, precipitation, snow) and impacts on tree species movements/dispersal are uncertain
Technological*	There is need for more rapid and affordable methods of identifying rust resistant individuals throughout the species' range
Sociopolitical: Policy & Management	Agency interpretation of Wilderness Act protections can constrain the 'toolbox' of management actions available and is uncertain across regions, parks, and agencies Feasibility of some conservation and management actions is limited by funding, resources, policy, and the clash of species-specific policies, creating uncertain action options Management tends to be reactive; proactive management to prevent disasters is not typically rewarded or reinforced, especially if it requires long-term investment - thus long-term funding uncertain

* Although we did not identify "Technological challenges" as a category during the whitebark pine workshop, we did specify this during the American pika workshop and we have included it here.

Table 1 (continued). Key drivers of whitebark pine population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in September 2015.

Category	Drivers and factors
Sociopolitical: Policy & Management (continued)	Low response preparedness for novel diseases, creating potentially long response times by management agencies - management response highly uncertain
	Need for education and outreach to managers, policy makers, and NGOs about the status and challenges of WBP ecosystems and the relevant changes that could be expected with continued rapid climate change
	Need for political leverage at the state and national levels by WBP researchers and managers to enact policy change and garner funding
Sociopolitical: Public	Public perception of active management in wilderness areas (e.g., planting, thinning, prescribed fire) will need to be addressed through outreach and communication
	Public, academic, and political debate over assisted migration is ongoing and will need to be addressed

* Although we did not identify "Technological challenges" as a category during the whitebark pine workshop, we did specify this during the American pika workshop and we have included it here.

Table 2. Key drivers of American pika population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in April 2016.

Category: Subcategory	Drivers and factors
Climate: Regional climate and climate change	Huge climatological variation across species range and within and among regions make range wide changes extremely uncertain
	The degree to which micro-climates are decoupled from meso/macro-climate conditions
	Seasonal climate changes (e.g., summer vs. winter) highly uncertain
	Directionality and consistency of climate changes and uncertainties vary depending on climate variable (temperature, precipitation, snow), season, and temporal and spatial scale
	Precipitation variation and trends highly uncertain
	Snowpack and snowmelt timing, and thus growing season length, are variable and highly uncertain
	Changes in growing season length are uncertain
	Climate-driven changes in hydrology can impact erosion, soils, and vegetation
Climate: Air quality	Impacts on pikas, predators, vegetation

Table 2 (continued). Key drivers of American pika population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in April 2016.

Category: Subcategory	**Drivers and factors**
Geological: Geological origins	Volcanic (e.g., Crater Lake National Park, Craters of the Moon National Monument and Preserve) vs. uplifted landscapes (e.g., Yosemite National Park, Sequoia & Kings Canyon National Parks)
	Patch substrate age - newer substrates are coarser and more open (inter-particle)
	Topography: High vs. low elevation, montane vs basin, ridge & valley (e.g., Sierra Nevada) vs. volcanic plains and slopes (e.g., Crater Lake National Park, Craters of the Moon National Monument and Preserve)
	Patch substrate/soil type and physical structural complexity of patches
	Soil accumulation and talus infilling rates - vary within and across regions, changes with climate and related weathering and hydrology are highly uncertain
	Physical microclimates of patches vary at multiple scales from high elevation granitic talus to low elevation volcanic lava flows - climate impacts are highly uncertain
Biological: "Lagomorph baggage" - phylogenetic constraints on species genetics and biology	Dispersal capacity within and between metapopulations - relatively unknown but likely limited
	Level of philopatry across populations and regions uncertain
	Extent of territoriality and solitary behavior unclear across populations and regions
	Communication - intraspecific calls - limits to patch colonization uncertain
	Individual mortality/longevity and patch turnover poorly understood and uncertain
	Disease resistance poorly understood
	Adaptive capacity and plasticity appear to vary between populations and locations, with some displaying high levels of both and others not so much
	Genetic diversity and connectivity within and between metapopulations variable and poorly understood across most populations and regions
	Complementary genes/alleles important for genetic conservation unknown and should be identified. Importance to regional adaptation and future refugia or assisted migration uncertain
	Genetics of physiological traits, physiological tolerances, and physiological plasticity poorly understood

Table 2 (continued). Key drivers of American pika population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in April 2016.

Category: Subcategory	Drivers and factors
Biological: Physiology and behavior	Haypiling varies between and within sites. Where present, related vulnerability to climate change with changes in vegetation composition, structure, distribution and winter temperatures is uncertain
	Dietary plasticity and digestion/metabolics relative to potential climate-habitat driven changes in food availability appears to vary between populations/locations
	Spatiotemporal variation and change in fecundity and fertility due to environmental stochasticity and demography among individuals and populations are uncertain
	The range of thermosensitivity and capacity for thermoregulation relative to climatological changes and interactions with microclimates are highly uncertain, especially across elevations/latitudes
	Climate impacts on pikas phenology (e.g., spring emergence), phenological synchrony across trophic levels, and resulting impacts on fitness are highly uncertain
Ecological: Paleo-Biogeography	Initial colonization of metapopulations and any associated founder effects
Ecological: Metapopulation isolation and persistence	Habitat connectivity and fragmentation -impacts of matrix composition, roads, fire uncertain
	Spatiotemporal habitat quality across patches unknown for most regions
	Genetic diversity and connectivity uncertain for most metapopulations
	Source-sink dynamics (dispersal capacity, predation risk, disease) unknown for most metapopulations
	Impacts of patch demographics such as age and sex ratios uncertain
	Inter- and intraspecific communication in patch detection or selection uncertain
Ecological: Patch isolation	Site (patch) survival, colonization and turnover rates - variation within and across metapopulations?
	Distance to edge and Edge-to-Area ratio effects uncertain
	Distance to other patches - topographic location impacts uncertain
	Access to vegetation - extremely large or deep rock/talus areas may have limited vegetation
	Impacts of changing growing season length on vegetation access is uncertain
	Precise description or measure of habitat patch quality for pika persistence is very challenging

Table 2 (continued). Key drivers of American pika population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in April 2016.

Category: Subcategory	**Drivers and factors**
Ecological: Vegetation	Impacts of climate on food availability, nutritional content and secondary compounds (habitat quality) unknown
	Invasive species impacts on community composition and structure is uncertain
	Impacts of interspecies competition, encroachment related to climate change is uncertain
	Impacts on predation risk due to changes in vegetation structure uncertain
	Soil type and condition, deposition rate, and topography interact to determine vegetation community and access to vegetation - climate impacts on these dynamics are uncertain
	Impacts of grazing and fire on vegetation abundance, community composition, structure
	Impacts of changing growing season length on vegetation composition and structure is uncertain
Ecological: Disease	Disease ecology is poorly known; climate impacts on disease emergence, prevalence, vectors, transmission rates unknown
	Potential for plague from rodents, dogs unknown
Technological	Uncertainty and confusion over different models of site occupancy turnover and extinction
	Difficulty identifying connectivity of patches, populations
	Detecting actual dispersal is extremely difficult
	Epidemiology and detecting mortality difficult - dead animals are rarely encountered
	Monitoring physiology, individual vital signs difficult as pikas are sensitive to capture and manipulation
Sociopolitical: Place-based values	Role as conservation icon of high elevation systems plays unknown role in acceptance of actions
Sociopolitical: The icon problem - icon as peril vs. persistence	When species become iconic people think that it is in trouble everywhere (e.g., panda, polar bear) - but some icons have the capacity to persist - understanding of this for pikas is unknown
	Can we create an opportunity to educate about the complexities of persistence and facilitate adaptation to future change?
	Can we set or reset public expectations after periods of disturbance?
Sociopolitical: Management challenges	Identifying geographic, landscape level indicators is challenging - What links the regions (similarities) and what makes them unique is uncertain
	Prioritization of actions and how to spend conservation dollars is needed

Table 2 (continued). Key drivers of American pika population and community dynamics and factors affecting their management and conservation that were identified during a scenario planning Orientation and Exploration workshop in April 2016.

Category: Subcategory	Drivers and factors
Sociopolitical: Management challenges (continued)	Single species constraints vs. landscape context is uncertain, especially across diverse regions Planning for change on large (geologic) time scales is difficult and untraditional - e.g., preparing for a "little ice age" or next glacial period, identifying potential re-expansion of pikas from current and future refugia and potential migration corridors - Is it unrealistic to incorporate this thinking into management? Public and management issues of assisted migration for pikas are uncertain - why, when, where, what? Need to consider management actions in terms of reward vs. risk - uncertainty restricts action due to associated risk - e.g., Assisted migration vs. increased functional connectivity - Can we create corridors to facilitate future migration (increase functional connectivity) rather than assisted migration? How can we remind managers and public that there are “Good case” scenarios for the future that could include increased funding, adaptive capacity, and persistence?

Climate drivers

Temperature

Significant challenges to actionable management decisions lie in uncertainties over changing climate. The most important climate factors identified were temperature and precipitation. Our **network regions are experiencing significant warming across all seasons**, ranging from +0.1 to +2.0 °F/decade, with the greatest warming in the winter months (Kunkel et al. 2013). Of the 289 national park units considered by the National Park Service Inventory and Monitoring Program’s landscape dynamics monitoring project (Landscape Dynamics), 99% are currently in the warmer end of the distribution for their historical range of variability for temperature variables while being at the lower end of the distribution for number of frost days (Monahan and Fisichelli 2014). In other words, relative to the past century, parks are warmer overall with less frost. Current climate conditions may be within the range experienced by WBP and pika populations, which may have undergone expansion and contraction from refugia (Millar, Heckman et al. 2014; Mitton et al. 2000) since the last glacial maximum (Galbreath et al. 2009; Millar et al. 2007). However, it is unclear if these species have sufficient phenotypic plasticity or genetic variability to withstand warming trends.

Loss of pika occupancy has been associated with average summer temperature (Stewart et al. 2015) and average temperature (Millar and Westfall 2010). However, pikas and WBP are also susceptible to warmer and drier winter conditions (Henry and Russello 2013; Iglesias et al. 2015).), although the fact that many pika populations persist in warm, low elevation habitats emphasizes the need for a better understanding of thermal limitation and habitat use in this species (Jeffress et al 2013; Shinderman et al 2015). Local and regional adaptation to temperature regimes may be critical for the conservation of both WBP and pikas. Cold adaptation is a trait that shows strong population differentiation across latitudinal and elevational gradients in WBP (Bower, McLane, et al. 2011), and pika populations include extreme elevational and latitudinal gradients (Rodhouse et al. 2010; Wilkening et al. 2011; Henry et al. 2012; Shinderman 2015). Therefore, local adaptation to temperature, whether physiological or behavioral, should be considered when conducting conservation actions, especially if they involve the movement of individuals or genetic material across populations and regions.

Precipitation

While temperatures, especially minimum winter temperatures, are showing an increasing trend in many montane and high elevation areas (Pepin et al. 2015), precipitation is far more variable, often without significant trends (Monahan and Fisichelli 2014). Future precipitation patterns under climate change are highly uncertain. Precipitation has been highly variable in Oregon, Washington, and Idaho since 1976 relative to the previous 75 years (Kunkel et al. 2013). While there are no significant trends in precipitation, recent years have been drier than 1901–1960, especially the dry periods of 2000–2002 and 2007–2009 (Kunkel et al. 2013). The Sierra Nevada recently experienced a severe drought from 2012-2015 that was in many ways unprecedented due to record-high temperatures coupled with low precipitation and these type of events are predicted to occur more frequently in the future (Ullrich et al. 2018). Uncertainty of future precipitation is compounding the uncertain expectation for drought conditions, fire regimes, and species interactions and distributions.

Snowpack and snowmelt

Even under average precipitation conditions, warmer winter temperatures are driving decreased snow pack and earlier snowmelt dates in many western mountain regions, which are compounded by corresponding periods of drought. These compounding factors may limit pika dispersal, connectivity, and gene flow (Henry and Russello 2013). Reduced snowpack is impacting other key factors, such as hydrology, species phenology, and growing season length (Mote 2006; Pederson et al. 2011; Barry and McDonald 2012). The specific impacts of these cascading changes on species physiology, productivity and survival, competition, predator–prey dynamics, disease, and parasitism may be extremely variable across species' ranges and are highly uncertain, potentially presenting serious threats to WBP and pika persistence.

WBP and pikas have experienced significant large-scale variations in climate since the last glacial maximum (Galbreath et al. 2009; Iglesias et al. 2015). Greater seasonality and associated changes in atmospheric circulation produced warmer summer temperatures and colder winter temperatures than we currently experience (Alder and Hostetler 2014) in the late Holocene or Anthropocene. WBP has declined over the past 12,000 years with decreasing summer solar irradiance and increasing winter insolation, while declining snowfall at lower elevations over this period restricted the five-needle pines to higher elevation bands (Iglesias et al. 2015). Likewise, pikas have undergone range contraction associated with Holocene warming in the southern portions of their range; however, more northern lineages may have undergone post-glacial expansions (Grayson 2005). Importantly, some populations persist in warm, low elevation habitats such as Lava Beds and the Columbia River Gorge (Jeffress et al. 2013; Shinderman 2015). The potential impacts of precipitation, temperature, and snowpack and snowmelt timing on WBP cone production, seed germination rates, and seedling growth and development, soil mycorrhizae, and pest and pathogen tolerance are highly uncertain and require more research and monitoring. Likewise, the potential impacts of precipitation, temperature, and snowpack and snowmelt timing on pika dispersal, spring emergence, forage phenology and quality, and seasonal physiological condition are also highly uncertain and require more research and monitoring, particularly in low elevation habitats that experience far less snow than high elevation habitats. Although recent research suggests little impact on annual survival of low snow years (Smith and Millar 2018), long-term monitoring will help us detect and assess any carry-over effects or time lags of warm, dry, or low-snow years on individual condition, productivity, and survival.

Geologic drivers

Geologic origins and topography

The geologic origin of a region or site was a uniquely important factor identified for pikas. The species range of American pika encompasses a vast diversity of geomorphic landscapes with distinct geologic origins, histories, and current topographic structures and processes. Important climatic variation is associated with these landscapes that present constraints on pika distributions (Jeffress et al. 2013) and the geologic legacy and resulting contemporary geophysical landscape present constraints of their own. This highlights one of the most important considerations for pika scenario planning: selecting appropriate time scales for monitoring, research and management. In lava landscapes, successive volcanic events may have had a greater influence on pika distribution than climate factors, particularly where local or regional-scale eruptions covered previously exposed habitat with cinders and ash of varying depth (Rodhouse et al. 2010; Shinderman 2015). These ash layers, and associated vegetation, fragment habitat in important (though not well understood) ways.

American pika occupy a wide diversity of landscapes across large elevational gradients with distinct geologic origins, including the high alpine talus slopes and steep valleys created by tectonic uplift of the Sierra Nevada Mountains, and those of volcanic origins, including Crater Lake National Park, Craters of the Moon National Monument and Preserve, Lava Beds National Monument, and Newberry Crater National Volcanic Monument (**Error! Reference source not found.**). There is also s ignificant variation among sites with volcanic origins. The rim of Crater Lake is more typical of “classic” high elevation, montane and subalpine habitat, with optimal habitat around 2000m elevation (Castillo et al. 2014) while Lava Beds and Newberry Crater are relatively low elevation, arid land dominated by pines, juniper, and shrubs such as sage and bitterbrush. There is also significant heterogeneity within low elevation volcanic landscapes, which differ in their underlying ‘pre-volcanic’ topography, prevalence of cones, tubes, and other volcanic features, and relative proportions of pahoehoe and a’a lava flows (Rodhouse et al. 2010). These and other geological topographic/geographic features may significantly limit dispersal of pikas (Castillo et al. 2016) and WBP (Richardson, Klopfenstein, and Brunsfeld 2002) although the complexities of this hypothesis specific to particular landscapes for pika needs to be further evaluated.

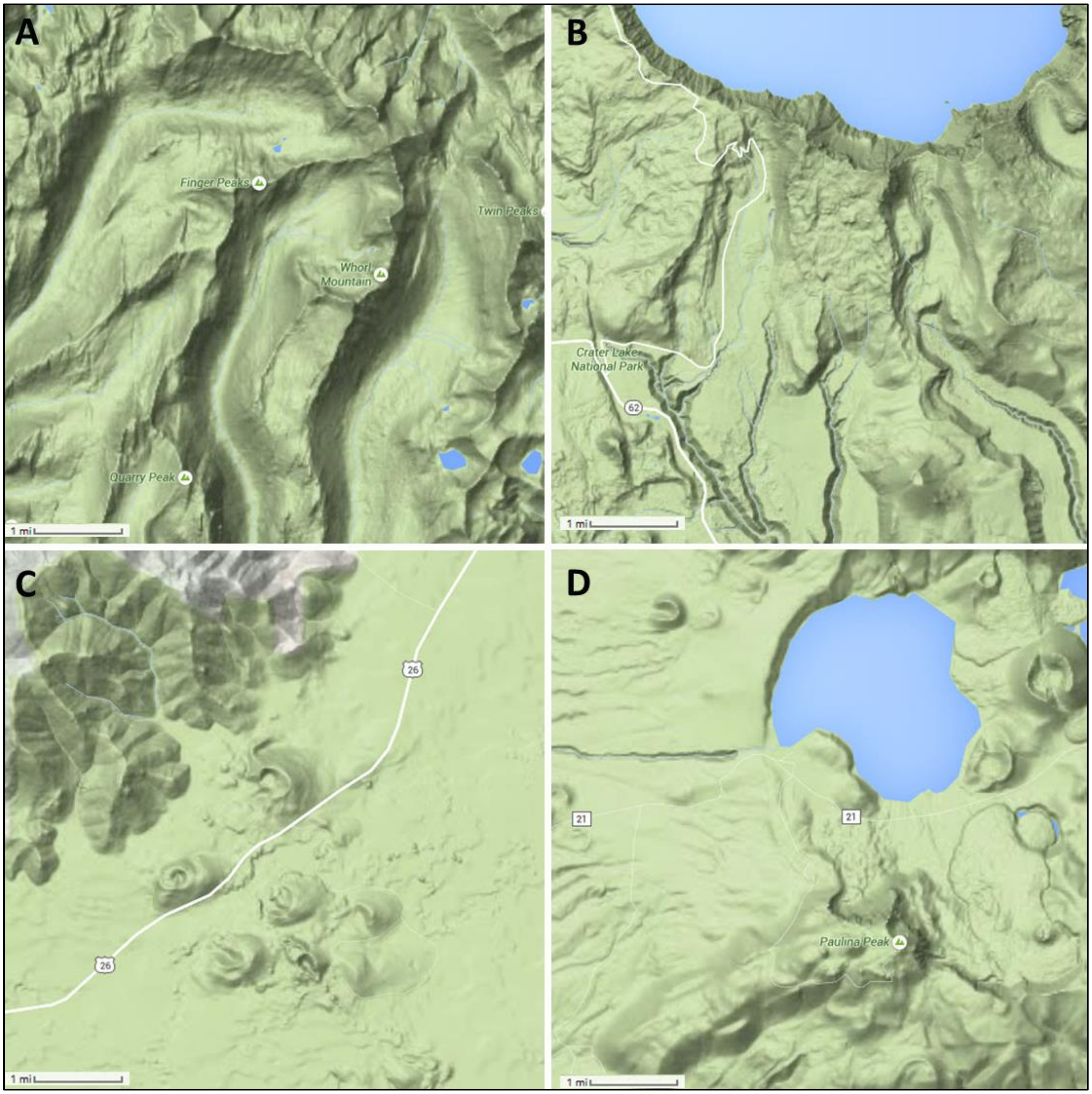

Figure 7. The geologic diversity of landscapes comprising portions of the species range of American pika. Factors unique to each landscape likely affect metapopulation and population dynamics and persistence. The geologic origins, current topography, and physical substrate structures of these landscapes include: A) steep, high elevation peaks, talus ridges, and valleys of the Sierra Nevada in Yosemite National Park, California, formed through tectonic uplift, B) relatively gentle moderate elevation volcanic slopes, pumice and boulder fields, and narrow creek drainages of Crater Lake National Park, Oregon, C) relatively low elevation lava flows of Craters of the Moon National Monument and Preserve in the foothills of the Pioneer Range, Idaho, and D) primarily a'a lava fields and volcanic cones of Newberry Crater National Volcanic Monument, Oregon. Not pictured, but providing another unique landscape and habitat type is the Columbia River Gorge (See Simpson 2009).

Patch substrate

At finer resolutions, the age and type of patch substrates may play important roles in pika occupancy (Millar and Westfall 2010). The substrate age, along with substrate type and size, will impact the physical structural complexity and soil type of patches along with the physical microclimates, with younger substrates being coarser with more inter-particle space and less soil accumulation (Millar, Westfall, and Delany 2014; Millar and Westfall 2010; Stewart et al. 2015) and thus habitat patch size. Furthermore, in volcanic landscapes, the age of lava flows have an important impact on the soil accumulation and vegetation growth and succession state. These factors all vary within and across populations and regions, but this variation is poorly understood across the wide range of geologic substrates pikas occupy. Impacts of changing precipitation, snowpack and snowmelt, fire dynamics, and vegetation communities on weathering, hydrology, and soil accumulation, retention, quality, and thus patch size, quality, connectivity, and accessibility are highly uncertain.

Biological drivers

Species' biology is central to understanding the potential impacts of environmental change, yet some fundamental aspects of biology and natural history and their potential responses to environmental change are poorly understood and highly uncertain for WBP and American pika. Life history traits such as individual growth, reproduction, and dispersal, and demographic and genetic factors such as genetic diversity, local adaptation, disease resistance, inbreeding, and population structure are understudied or even unknown at the population and species levels in many cases. Dispersal capacity, local genetic diversity and adaptation, and population structure are particularly important research and monitoring needs.

Life history

Evolutionary life history is fundamental to understanding how WBP and pikas will respond to change. For example, low growth, long generation times, and great longevity of WBP (Perkins and Swetnam 1996) are key traits that have facilitated population persistence for millennia. However, these same traits may limit WBP capacity to adapt to rapid contemporary environmental changes because traits that affect a tree's tolerance to abiotic stressors, such as frost and drought, likely have greater impacts on fitness than those related to competitive ability such as height or growth rate (Bower and Aitken 2008). Species with long generation times such as WBP can have limited capacity for local adaptation to keep pace with rapid climate change, however, for Great Basin long-lived conifers, the regeneration state is generally considered to be most vulnerable – and thus conditioning – the response to climate. Seedlings that survive to their first decade, are likely to survive through maturity, other disturbance factors notwithstanding (Millar, Westfall, Delany, et al. 2015; Smithers and Smithers 2017). Thus, in fact, despite the long generation time, long-lived species can be very fast-paced in response to environmental change if regeneration is able to occur. Although the paleoecological record indicates that the primary response of plants to past climate change has been migration, while evolutionary adaptation has played a relatively minor role (Huntley 1991), bristlecone pine has maintained persistence within its current elevational zone for at least 11,000 years. Under contemporary conditions the maximum migration rates of many long-lived tree species may fall short of the current rate of climate change, necessitating management actions for some species or populations (Huntley 1991) however, limber pine has shown rapid migration capacity in the Great Basin (Millar, Westfall, Delany, et al. 2015; Smithers and Smithers 2017). These concerns and their counter examples emphasize our need for knowledge of local responses and adaptation within and among populations and the genetic diversity and geographic differentiation in traits related to growth and temperature adaptation (Bower and Aitken 2008) and regional climate refugia (Millar, Westfall, Evenden, et al. 2015).

All species are, to some degree “saddled with evolutionary baggage”. In other words, they are phylogenetically constrained in their biological, genetic, and thus adaptive responses to change (Niu et al. 2004). For pika, aspects of their physiology, behavior, and ecology are the product of their evolutionary origins within the Lagomorph order. Hares, rabbits, and pikas have adapted to a huge range of habitats. It is interesting to consider that part of the evolutionary “baggage” of pikas is that their evolved habitat is talus and related rocky landforms, which have decoupled ventilation systems that support in their matrices cool, equable summer conditions and warm winter conditions (Millar et al. 2014, 2016). Just as humans move into air-conditioned habitat when the mercury rises, it seems that the evolved condition of inhabiting taluses gives pikas a unique potential for plasticity despite their temperature sensitivity and thus are able to exploit otherwise untenable environments.

None-the-less, like WBP, pikas are still may be highly constrained by their temperature sensitivity through its impacts on dispersal capacity, although the relationship between thermal sensitivity and dispersal may be variable and idiosyncratic across populations. Consider, if pikas can live at high elevations in relatively pristine environments and low elevations in much warmer highly modified environments, how do we understand constraints related to temperature sensitivity? Pikas continue to persist in areas where ambient air surface temperature alone would suggest they shouldn’t, but habitat features provide adequate thermal buffering. Pikas have adapted to an incredible diversity of habitat through selection of microclimates of rock and talus to behaviorally regulate temperature and avoid exposure to extreme high and low temperatures during the day and throughout the season (Smith 1974). Winter snowpack also provides further thermoregulation to insulate them from extremes of surface temperatures within subsurface habitats (Millar et al. 2014, 2016; Yandow et al. 2015). Therefore, just like a person forced to leave their climate controlled home in the heat of summer or dead of winter, **warmer temperatures during phenologically critical dispersal periods could be limiting the inherently low dispersal capacity for adult and juvenile pikas** through direct impacts of thermal surface exposure and loss or vertical narrowing of thermally ideal subsurface microclimates within the substrate.

There has been a predominant hypothesis in the American pika literature predicting that reduced snowpack and early snowmelt due to climate change will increase pika mortality of higher elevation montane populations through the loss of the insulative snow layer during winter, creating metabolic strain due to increased thermoregulative demands. Research following the dramatically dry winter of 2014-15 where the Sierra Nevada received its lowest snowpack in recorded history, found that contrary to this prediction, patch occupancy of pikas remained nearly constant (Smith and Millar 2018). Considering pikas persist within much warmer low elevation habitats, perhaps pikas have a much great thermal plasticity and/or the thermal buffering of their habitat is more effective than we understand. However, we should acknowledge that while metabolic stress in one season alone may not increase mortality detectable the following season, there may be time lag effects, cumulative effects of multiple low snow years, or interactions with other stress factors (e.g., disease, food availability) in some years. It is uncertain how thermal sensitivity impacts dispersal and survival in warm, relatively dry, low elevation populations in areas such as Lava Beds National Monument, Newberry Crater National Volcanic Monument, Craters of the Moon National Monument and Preserve, and the Columbia River canyon. Models of habitat occupancy, and likely survival, do not adequately apply to these sites (Shinderman 2015; Simpson 2009; Smith and Millar 2018). It is also unknown how environmental changes that impact pikas' ability to thermoregulate impact fitness through fundamental vital rates such as productivity and survival.

Demography and population genetics

We are also lacking fundamental knowledge of adaptive capacity, phenotypic plasticity, genetics of physiological traits and tolerances, and genetic diversity and connectivity of WBP and pika populations. Inherent adaptive capacity reflects the evolutionary mechanisms and processes that allow organisms to adjust to changing environmental conditions and depends on intrinsic factors including genetic diversity, phenotypic plasticity, and dispersal and colonization ability (Dawson et al. 2011). Ultimately, genetic diversity determines the underlying potential for organisms to adapt to changing environments. An understanding of geographic variation in genetic diversity and functional connectivity within and among populations is a critical component to WBP and American pika conservation (Bower, Richardson, et al. 2011; Castillo et al. 2016), yet we lack information for many populations.

Local adaptation and tolerance

Responses of WBP and pika populations to rapid climate change are essentially limited to three possibilities: (1) local persistence through adaptation to new conditions at their current location, (2) spatial movement to track conditions that comprise their ecological niche through either *in situ* shifts in microclimates or longer-distance migration to suitable regions, or (3) population extirpation (Aitken et al. 2008). The first two responses could be supplemented, facilitated, or expedited. Efforts for WBP and other pine and tree species have been undertaken through identification, cultivation, and outplanting of adaptive seed types (Sniezko, Kegley, et al. 2011), assisted migration experiments (McLane and Aitken 2012), and assisted gene flow which can mitigate maladaptation to climate change. However, assisted migration can also cause outbreeding depression, and disrupt local adaptation to non-climate related conditions (Aitken and Bemmels 2016; Aitken and Whitlock 2013). Therefore it is important that projects attempt to accurately detect signatures of local adaptation using genetic-environment associations through study designs that minimize collinearity between climatic gradients and neutral structure in natural populations and maximize climatic variation (Nadeau et al. 2016). Scientists and managers are developing user-friendly decision making tools for climate-adjusted restoration efforts in some regions, such as web-based GIS approach for choosing seed provenance in ecological restoration.

The likelihood that any given species or population will respond via adaptation or migration depends on its adaptive capacity, dispersal and colonization abilities, and functional connectivity. Pikas and WBP have very different dispersal processes and capacity, although both are constrained by unsuitable habitat that may be expanding at rates that exceed potentials of these species. The geographic range of WBP has closely tracked climate changes related to glaciation since the late Pleistocene (Richardson, Brunsfeld, and Klopfenstein 2002). WBP is dependent on Clark's Nutcrackers for seed dispersal, which effectively move seeds within populations, but only rarely make extrapopulation movements beyond 20 km (Richardson, Klopfenstein, and Brunsfeld 2002). Occasional long-distance jump dispersals may have been sufficient to track glacially driven climate changes of the late Pleistocene and early Holocene Epochs but may be insufficient under rapid contemporary climate change, habitat loss and degradation.

Dispersal and gene flow of pikas in some alpine habitats may be restricted by topographic relief, water and west-facing aspects, suggesting that physical limitations could be related to small body size and mode of locomotion and physiological tolerances to warmer temperature exposure (Castillo et al. 2014). Dispersal dynamics for pikas in low elevation sites subject to higher temperatures are uncertain, but these populations may be even more dependent on thermal microclimates of substrates such as lava and boulder fields or cliffs (Smith 1974).

Although we understand the basic natural history of dispersal for these species, we still lack thorough understanding across the diverse elevational and latitudinal ranges of both species, limiting our ability to make predictions at scales relevant to park units.

A critical need for effective management is data on traits associated with response to and tolerance of abiotic factors. As mentioned earlier, these tend to have greater fitness impacts than those related to competitive ability (Bower and Aitken 2008). However, there can be complex growth-by-climate interactions with lagged responses (Millar et al. 2012). For example, cold adaptation (date of needle flush and fall cold injury) is an important adaptive trait for WBP (Bower and Aitken 2006, 2008). Grown in a common garden, seedlings from populations adapted to colder climates had greater cold adaptation than those from milder climates, which grew taller but had lower freezing tolerances than those from the harsher regions (Bower and Aitken 2008). Populations from lower elevations and higher latitudes had greater growth potential (Warwell et al. 2006). During tree die-offs, surviving stands of trees were better able to take advantage of increasing temperature and decreasing water stress by growing faster than trees that died (Millar et al. 2012). Therefore, there appear to be evolutionary trade-offs between growth and traits related to cold tolerance and water stress, which may represent the climate conditions that were dominant when that genotype established. Furthermore, these may represent distinct genotypic groups that have differential responses to temperature and water stress (Millar et al. 2012). In pikas, temperature-related abiotic factors may interact with animal behavior to influence survival, occupancy, and persistence. For example, dispersal and connectivity may be constrained by patch aspect, elevation, and snowfield characteristics (Castillo et al. 2016; Henry and Russello 2013), but this hypothesis needs further research across the diverse habitats of pikas' range. Furthermore, there may be variability and interaction with age demographics, for example the phenology of juvenile dispersal being more limited (Smith 1974).

It is extremely important to note that scenario planning for pikas and a somewhat lesser extent WBP, will almost certainly require a **place-specific approach** given documented variability in occupancy patterns, population trends, behavior, diet/nutrients, and persistence (Jeffress et al. 2013). If anything, it is very clear that what holds true for one population does not for others. An appropriate conservation model may be The Nature Conservancy's Conservation Action Planning (CAP, formerly 5-S, Table 3), wherein identification of stresses - degraded key ecological attributes that are outside their acceptable range of variation - is a key component of long-term conservation success, particularly when stress-specific mitigation strategies are developed (TNC 2007). Pika conservation (and monitoring) will likely require a similar approach, keeping in mind that stresses and sources of stress will vary between and sometimes within park units.

Table 3. Definitions of stress defined by the Conservation Action Planning Handbook of The Nature Conservancy (TNC 2007).

Term	Definition
Stresses	Impaired aspects of conservation targets that result directly or indirectly from human activities (e.g., low population size, reduced extent of forest system; lowered groundwater table level). Generally equivalent to degraded key ecological attributes (e.g., habitat loss).
Sources of Stress (Direct Threats)	The proximate activities or processes that have directly caused, are causing or may cause stresses and thus the destruction, degradation and/or impairment of focal conservation targets (e.g., road construction).
Critical Threats	Sources of stress that are most problematic.

Genetic diversity

Genetic diversity is critical to species and population conservation. Low or declining genetic diversity and inbreeding depression are associated with population decline and extinction risk (Frankham 2005; Spielman et al. 2004). Genetic diversity also tends to be lower at more northern latitudes and in areas of greater human disturbance (Miraldo et al. 2016).

Overall, genetic diversity of WBP varies throughout its range but tends to be much greater within than among populations. Studies using neutral markers (e.g., isozymes) show most genetic diversity to be within groups and less than 5% of genetic variation between groups. Mahalovich and Hipkins (2011) found only 1% of genetic variation between "seed zones" using isozymes and about 3% using chloroplast DNA (cpDNA). Examination of allozyme loci in the eastern Sierra Nevada found that genetic variation is highly structured; within krummholz thickets, multiple individuals are present and genetic relationships often resemble half- to full-sibling family structure with the greatest genotypic variation in the direction of the prevailing wind, indicating that genetic structure is profoundly influenced by the seed-caching behavior of Clark's Nutcracker (Rogers et al. 1999). Genetic diversity also appears to be greater in the eastern part of the WBP's range than the west (Jorgensen and Hamrick 1997); however, regional populations in British Columbia have slightly higher diversity, perhaps due to multiple founder effects (Krakowski 2001; Krakowski et al. 2003). Diversity is somewhat lower in the Olympic Peninsula than the Cascade Mountains of Oregon and Washington (Bower, McLane, et al. 2011).

Despite the relatively low diversity among groups, population differentiation is discernable and should play an important role in species conservation and restoration actions such as outplanting and *ex situ* genetic conservation for WBP. Populations in the western region of the species in the Cascades and Sierra Nevada were found to be genetically discernable from the eastern region of the Rocky Mountains and Great Basin, but differed by only 7.7% (Jorgensen and Hamrick 1997). Based on the mitochondrial genome of WBP, two haplotypes were identified in the interior West, with one in Idaho, Montana, eastern Washington, and Wyoming and the other in eastern California and Washington (Mahalovich and Hipkins 2011). Mean date of needle flush was over three weeks later in southern Oregon than in northern Washington and British Columbia (Bower, Richardson, et al. 2011). Genetic adaptation in height growth to regional precipitation and phenological responses to seasonal temperature lead to the identification of at least eight seed zones in Oregon and Washington within which seed transfer should be restricted (Hamlin et al. 2011). However, there can be a high level of genetic diversity among families within any zone, which may prove useful for outplanting conservation efforts to buffer against climatic and other environmental change.

Mitochondrial DNA analysis of pikas range wide has revealed five distinct lineages associated with mountain ranges (Galbreath et al. 2009). These lineages can be recognized as five evolutionarily meaningful subspecies that should be considered in management actions (Hafner and Smith 2010). Therefore, our three National Park Service Inventory and Monitoring Network regions encompass at least three subspecies (Hafner and Smith 2010). Range expansion occurred following the last postglacial maximum along the Cascade/Coastal mountain ranges of Oregon, Washington, and British Columbia. Northern populations exhibit lower genetic diversity relative to their closely related southern populations from nonglaciated regions (Galbreath et al. 2009; Henry and Russello 2013). Current gene flow of high elevation montane pika populations may be constrained by landscape and topographic barriers associated with greater thermal exposure (Castillo et al. 2014) consistent with evidence of gene flow patterns during interglacial oscillations, where cooler periods facilitated genetic cohesion of lineages. However, in "nontraditional" highly-disturbed, warm, and/or low elevation habitats, topographic barriers do not necessarily seem to preclude dispersal emphasizing the need for research across the diverse habitat range (Manning and Hagar 2011).

Dispersal

Dispersal in pikas is primarily limited to juveniles, who typically disperse no more than 2–3 km and usually much less (Smith 1974; Peacock 1997; Smith 1987). Philopatry and high territoriality also contribute to inbreeding and low heterozygosity in populations (Galbreath et al. 2009; Henry and Russello 2013; Smith and Weston 1990); however, high individual turnover and low genetic differentiation (FST) among neighboring populations suggest at least occasional longer distance, possibly jump dispersal events in some populations (Peacock 1997).

In WBP, the clustering of closely related full to half-siblings as a result of Clark's Nutcracker seed dispersal can result in a fairly high rate of inbreeding (Jorgensen and Hamrick 1997), but family relationships may vary with elevation and region. Rogers et al. (1999) found that low elevation tree clumps contained more than one genotype while family relationships were closer within krummholz tree thickets. However, during a common garden experiment, Bower and Aitken (2007) detected no inbreeding depression in growth traits of trees from Oregon and Montana source populations and depression only in the biomass trait for progeny from a southern British Columbia population. There may be selection against inbred progeny, but it is unclear whether this occurs during seed development, germination, emergence, or by affecting fecundity or tolerance to environmental factors (Bower and Aitken 2007).

Ecological drivers

Our two focal species have some very species-specific ecological drivers of change and threats to persistence. Important data are lacking for both species, however, on community interactions, patch characteristics, habitat quality, and disease ecology and the interacting and compounding impacts of environmental change on these factors.

Metapopulation and patch dynamics

Central to the conservation of pikas are factors driving metapopulation and patch isolation and persistence, yet we are lacking this information across spatial scales throughout much of the species' range. Understanding dispersal is central to our understanding of patch, population, and metapopulation connectivity; however, there are few direct measures of dispersal (Peacock and Ray 2001; Smith 1974). Functional connectivity revealed through genetic analysis is variable and we lack information for many regions (Castillo et al. 2016; Galbreath et al. 2009; Henry et al. 2012). Founder effects, the role of matrix composition, source-sink dynamics, variation in patch survival, colonization and turnover rates (Smith and Nagy 2015), spatiotemporal habitat patch condition, patch distance and edge-to-area ratios, and use of marginal habitats are almost unknown throughout most of the pika's range, making the impacts of environmental change uncertain. An equally important factor is that vegetation successional changes, particularly in lava environments, may have as much or more impact on site occupancy. Most of these changes will be influenced to some degree by current and future climate conditions, but some degree of vegetation community change would occur irrespective of anthropogenic climate change. The combined paleo-distribution of American pika and geologic history of Central Oregon suggest a very strong relationship between site occupancy and vegetation community change associated with soil/ash deposition events. Whether the plant community change is a direct or indirect driver of changes in site occupancy remains to be seen, but the signal is getting clearer with increasing research across the diverse range of pika habitats.

Pests, disease, and resistance

The most significant threats to WBP population persistence involve the ecological dynamics of white pine blister rust (WPBR) and mountain pine beetles (MPB), along with the interacting and possibly exacerbating factors of changing fire regimes and elevation-dependent warming associated with climate change. While these concerns are universally shared by scientists and managers working with WBP throughout the species' range, the relative current and future roles of these factors in shaping the future of WBP are extremely complex and highly uncertain in western populations. The relative importance and impacts of these factors depends on the relative local prevalence of each, the time scale of consideration (e.g., years vs. decades), as well as interactions with each other across multiple scales, and management actions, such as pest control and resistance breeding programs. For example, in Yosemite National Park, WPBR and MPB prevalence and resultant tree mortality are lower than in the Oregon Cascades (Nesmith et al. 2019). A recent range wide study of WBP in the US found that while whitebark pine occurred across 4.1 million ha, 85% of this area and 72% of whitebark pine seedlings were located within forest types other than the whitebark pine type (Goeking et al. 2018). This reflects not only biogeographic heterogeneity, but also important differences in priorities, resources, management targets and perspectives across management boundaries and sociopolitical atmospheres.

White pine blister rust – genetic diversity and resistance

WPBR was inadvertently introduced to North America from Europe during the late 19th and early 20th centuries with imported eastern white pine (*Pinus strobus*) (Spaulding 1911). This fungal pathogen has a complex life cycle requiring two alternate hosts. Ultimately, spores that infect needles and germinate send hyphae into the tree's vascular system, ultimately girdling branches and stems (Kinloch 2003; Geils and Vogler 2011). WBP conservation efforts are focusing heavily on identifying and breeding genetic sources with rust-resistance, which confers the ability to survive repeated infections (Sniezko et al. 2004; Mahalovich et al. 2006; Sniezko, Mahalovich, et al. 2011). Even in operational contexts, incorporating rust-resistant sugar pines at a conservationally effective scale in California over four decades, has been an enormous challenge and incurred tremendous cost. Natural resistance is variable across WBP regions and populations and not well known for many parts of the tree's range. The US Forest Service Dorena Genetic Resource Center (DGRC) is actively screening seed collections from Oregon and Washington for genetic resistance to WPBR. In 2003 Crater Lake National Park began monitoring WBP and collecting seed for resistance testing at DGRC. The park has since conducted outplanting and monitoring of rust resistant seedlings, along with other pest management actions, through their Whitebark Pine Conservation Program (Beck 2015). An extensive list of publications from DGRC is available at https://www.fs.usda.gov/detail/r6/landmanagement/resourcemanagement/?cid=stelprdb5280987.

Uncertainty regarding WPBR resistance is increased further due to distinct population structure in WPBR. There are complex host-pathogen interactions occurring at the genetic level, and there is spatial variation in resistance across pine populations. Genetic diversity of WPBR is 2–5 times higher in eastern U.S. than western U.S. populations. This is likely due to repeated pathogen introductions in susceptible pine populations of the northeastern United States during the early 20th century and only one or few in the West, as well as the geographic barrier of the Midwestern prairie and Great Plains (Hamelin et al. 2000; Brar et al. 2015). Overall, genetic diversity in WPBR is low, while population differentiation is high, but it is not spatially associated with geographic distance (Kinloch et al. 1998) as it is in WBP (Richardson, Brunsfeld, and Klopfenstein 2002). Pine host populations are highly fragmented, separated by barriers to gene flow and host connectivity such as mountain ranges. Likewise, western WPBR appears to be a fragmented metapopulation driven by frequent founder events through moderate to long-distance aeciospore dispersal. This is consistent with the nonuniform spatial mosaic of occurrence and intensity of infection, especially in the Klamath, Cascade, and Sierra Nevada Mountain regions (Kinloch et al. 1998). There is further differentiation between natural stands and tree plantations (Brar et al. 2015), which suggests that there is still anthropogenic dispersal of WPBR in the United States. Transportation and outplanting of pine seedlings, as well as commercial *Ribes* production, should be carefully screened for the pathogen to avoid pathogen migrations and shifts in pathogen races. This is especially important in movements between eastern and western populations or in introductions from Asia or Europe that could lead to "genetic bridges" and novel adaptations (Kinloch et al. 1998; Hamelin et al. 2005; Brar et al. 2015).

Climate factors are also relevant to dispersal of WPBR spores and the frequency and severity of rust outbreaks. So called "wave years" result when aeciospores released during a cool moist spring is followed by frequent cool, moist infection periods during the summer, facilitating numerous cycles of urediospore multiplication (McDonald et al. 1981; Mielke 1943). The cool moist weather also facilitates teleospore germination and pine infection by basidiospores. The dynamics of future "wave years" may be particularly relevant to the Parks network, given the latitudinal gradient from mesic to drier conditions represented by the parks.

White pines show evidence of major gene resistance (MGR or R-gene) and partial resistance, as well as induced rust resistance, which could impact the genetic structure of WPBR (McDonald et al. 2004; King et al. 2010). Resistance in northwest intermountain populations increases from southeast to northwest, which is the opposite of the spatial trend in cold hardiness (Mahalovich et al. 2006). In Oregon and Washington resistance increases south to north (Sniezko, Mahalovich, et al. 2011). Pine hosts with major gene resistance (MGR or R-gene) reduce WPBR genetic diversity, while hosts with multigenic resistance have no apparent impact. Meanwhile, virulent races of WPBR have been discovered that can overcome rust resistance through a highly species-specific gene-for-gene interaction between white pine hosts and the pathogen (Kinloch Jr. and Dupper 1987; Kinloch et al. 2004), although these virulent races seem currently to be spatially and ecologically restricted (Kinloch et al. 1998). Again, these complex spatiotemporal genetic dynamics are not well understood through most of the WBP–WPBR range. This creates great uncertainty in management and requires further genetic research and sampling and faster techniques to quickly identify rust resistant individuals in the context of other important locally adaptive traits, such as thermal and drought tolerance.

A major concern expressed by members of our WBP workshop, especially resource managers, was the time and cost of developing rust-resistant seedlings for introduction through breeding programs. The production of rust-resistant trees requires substantial time, money, technical expertise, and resources, which may represent a substantial obstacle for many management plans and budgets. Even if funding existed currently to support such a program, there is significant uncertainty over whether that funding would continue for the required duration of such a project. Therefore, alternative proactive intervention actions that may be more feasible and attainable in the short term, and that may facilitate future seedling introduction actions, are desirable.

White pine blister rust vs mountain pine beetle

How should limited funding for management actions related to pest/disease management be allocated, especially when there is an emphasis on near-term verses long-term investment? A critical uncertainty in WBP persistence has been the relative demographic contributions of --and potentially complex interactions between-- MPB and WPBR as mortality agents on WBP demographics in the near versus long-term, which requires detailed, long-term monitoring data on host demographic rates and the incidence of pathogens causing mortality. Only recently has this issue been directly addressed with demographic research. Monitoring at Crater Lake National Park showed that deterministic and stochastic growth rates of WBP are declining by about 1.1% per year (Jules et al. 2016), although growth rate is not necessarily an indicator of high vigor or fitness. Removing trees with blister rust from models did not significantly change the growth rate ($\lambda < 1$); however, removing MPB-infested trees dramatically increased population growth ($\lambda > 1$) (Jules et al. 2016); which could be a factor of silvical thinning and/or genetic selection (Millar et al. 2012). Life-table response experiments revealed that the loss of the three largest size classes of trees to MPB had the greatest impact on population growth rate (Jules et al. 2016). This would suggest that immediate efforts to control MPB in WBP stands would benefit tree vigor, preserve structural and age diversity, and thus foster greater resilience and adaptive capacity of the stand to withstand and naturalize WPBR invasions (Schoettle 2004; Schoettle and Sniezko 2007). A critical distinction is that MPB can often kill trees far more quickly than WPBR. While efforts to develop blister rust-resistant lines is undoubtedly critical (Hoff et al. 2001; Keane and Parsons 2010), it must be considered in local contexts of immediate threats, costs, and management timelines. While developing genetically rust-resistant strains of WBP is thought to be a critical step for white pine conservation and management (Keane et al. 2017), it is complicated, time intensive, and expensive (McDonald et al. 2004; Sniezko, Kegley, et al. 2011; Vogan and Schoettle 2015), whereas using the chemical verbenone to protect WBP stands from MPB is relatively easy and inexpensive (Bentz et al. 2005). Therefore, immediate MPB management actions may represent proactive management for WBP during active beetle outbreaks.

Emerging diseases

One related potential driver of change for both WBP and pikas is the threat of novel and emerging diseases. Tourism, pets, and agricultural imports alone present enormous opportunity for increased pathogen dispersal and disease transmission rates, especially for fungal diseases (Fisher et al. 2012). Climate change can affect all levels of the complex interactions among pathogens, their hosts, the vectors with which many pathogens have mutualistic symbiotic relationships, predators, and catalysts (Hofstetter et al. 2015), further complicating our ability to predict future disease impacts. Increasing atmospheric carbon dioxide could increase biomass and microclimate relative humidity, promoting plant diseases like blights, leaf spots, rusts, and powdery mildews, and increasing inoculum potential across years. Increasing ozone could negatively impact plant growth, facilitating colonization of weakened trees by necrotrophic pathogens (Manning and Tiedemann 1995).

Very little is known about disease in pikas (Wilkening and Ray 2016), although 66 species of ectoparasites have been documented on American pika (Severaid 1955) including fleas which can carry plague. Flea load was negatively related to annual survival in a stress hormone (glucocorticoid) study of pikas (Wilkening and Ray 2016). Plague has been detected in Mongolian pika (Galdan et al. 2010), and could play a role in recent US pika extirpations (Biggins and Kosoy 2001). Plague and other diseases with animal vectors could be also be introduced to pika populations by pets or the expansion of other animal’s ranges, such as rats. Pikas also host helminth communities (Hobbs 1980), but whether they significantly compromise animal health and survival is not known. Disease and parasite burdens can be a significant stressor for animals and higher concentrations of the stress hormone glucocorticoid has been strongly associated with reduced annual survival (Wilkening and

Ray 2016). Emerging diseases is an area of huge uncertainty worldwide. There is significant concern over low response preparedness for novel diseases, creating potentially long response times by management agencies.

Another concern with high uncertainty is the potential for epizootic outbreaks of emerging, novel, or introduced diseases that could impact Clark's Nutcracker (CLNU) populations, the mutualistic seed disperser of WBP (Lanner and Vander Wall 1980; Tomback and Kramer 1980; Tomback 1982). West Nile virus (WNV) is prevalent in corvids, with some species, such as the American Crow (*Corvus brachyrhynchos*), declining 30–100% since the arrival of WNV circa 1999 (Komar 2003; LaDeau et al. 2007). Corvids have also been identified as an important factor in WNV amplification in southern California (Reisen et al. 2006). Much of our knowledge of WNV mortality in wild birds comes from public reports. Therefore, they must be considered in the context of detection probability. These voluntary reports are more likely to detect mortality in common and widely distributed corvid species abundant in developed rural, suburban, and urban areas, such as crows, rather than the CLNU, which is limited to montane forests that are either comparatively remote protected public lands or sparsely populated private lands. Nonetheless, there have been detections of CLNU mortality from WNV (David et al. 2007), although the prevalence of the disease and level of mortality are unknown. WNV could exist as an enzootic disease, with the possibility for future epidemic outbreaks of current strains or the emergence of new viral strains.

Fire

There is strong evidence of rapid climate driven changes to fire regimes in the Pacific West, though the rate and scope of these changes is highly uncertain and dependent on climate, ecology, management, policy, and sociopolitical perspectives (Parks et al. 2016; Schoennagel et al. 2017). Forest types with different natural fire regimes (fire severity, frequency, and size) are responding differently to longer fire return intervals (Steel et al. 2015). High elevation regions where both WBP and pikas persist could be considered both fuel and climate limited, due to a lack of fuel accumulation and a short growing season, lingering snow pack, cold temperatures, and severe weather (Coop and Schoettle 2011; Jenkins 2011; Kipfmeuller 2003). Fires in these systems tend to be small, low severity, and relatively infrequent. However, drought, declining snowpack, and increasing temperatures are altering many high elevation ecosystems, fostering encroachment by tree species typically restricted to more hospitable, lower elevation vegetation communities and colonization by native as well as invasive forb and shrub species (Dennison et al. 2014). Encroachment and invasion can increase ground and ladder fuels, creating fire dynamics and regimes to which WBP may be poorly adapted (Amberson 2013; Keane and Loehman 2010).

Fires do not appear to be detrimental to pikas. During one fire, temperatures in talus microclimates remained low (below 19°C), apparently allowing pikas to survive in situ and within 2 years pikas were widely distributed throughout burned areas. Pika densities were better predicted by topographic variables than by metrics of fire severity (Varner et al. 2015).

Mycorrhizal communities

Microbial soil communities are central to understanding ecological mechanisms of regulatory land-atmosphere carbon exchange and community response to climate change. To understand terrestrial carbon cycle–climate feedbacks, we need to consider direct and indirect impacts of climate change on microorganisms and the extremely complex interactions and feedbacks between microbes, plants and animals, and the abiotic environment, as well as other global changes that can amplify climate-driven effects on soil microbes, such as fire (Bardgett et al. 2008). Experimental evidence of microbial soil community response to climate change that would best inform predictive models and management actions alike are severely lacking (Bardgett et al. 2008), as are basic distributional maps of soil microbe communities within current five-needle pine ranges and potential future colonization sites. This is further complicated by the fact that correspondence between above- and below-ground views of species composition, spatial frequency, and abundance based on sampling fruit bodies and ectomycorrhizae is imprecise at best at the community level (Gardes and Bruns 1996).

Our team acknowledged that soil properties, especially mycorrhizal communities, and drought may limit tree species movements in response to climate change, but complexity and lack of information in many regions create high uncertainty in our ability to understand future impacts on high elevation plant communities. This has important implications for WBP and potentially for key plant species comprising pika habitat. Ectomycorrhizal fungi (ECM) are required for the survival of five-needle pines, and fewer than 50 of the ~10,000 ECM fungal species are known to be associated with WBP (Taylor and Alexander 2005; Mohatt 2006). Since ECM fungi differ in their soil preferences, dispersal, nitrogen and phosphorus dynamics, and other symbiotic benefits (e.g., pathogen and drought protection), it is extremely important that biodiversity of these beneficial fungi communities is maintained and encouraged through good management practices (Keane et al. 2012).

Influence of livestock grazing

Very little research has been done on the impacts of livestock grazing on pika populations. In actively grazed vegetation adjacent to talus bases (forefields) of the eastern Sierra Nevada and Great Basin mountain ranges, mean distance from talus borders to the closest fresh haypiles was over 16 times further (>30 m) than in ungrazed forefields and haypiles were found only high in the talus (Millar 2011). However, in ungrazed forefields, haypiles were found along the low-elevation talus–vegetation border (Millar 2011). Furthermore, haypiles at actively grazed sites consistently contained vegetation gathered from plants growing within the talus, which appeared to be of lower diversity and lower nutritional value than forefield plants (Millar 2011). Plateau pikas in Nepal, Tibet, and China are considered a pest and there are active poisoning programs to control populations. Inside fenced areas that excluded livestock grazing, standing plant biomass was higher and winter survival was greater than in grazed areas (Pech et al. 2007). Domestic livestock grazing is widely permitted on public lands in the U.S., however there is geographic variation in the restrictions related to elevation, habitat, and land management agency. This variation in grazing could contribute to some of the observed regional differences in viability of pikas (Millar 2011). In the Sierra Nevada, extensive historic livestock grazing occurred in subalpine meadows and adjacent habitat through the late 19th century. Grazing effects from sheep and cattle are thought to have had profound effects in some cases on plant communities (Dull 1999), though the impact on WPB specifically is unknown.

Technological drivers

Our ability to gain scientific knowledge is often limited by technological challenges. Telescope and microscope technology has allowed us to peer into the depths of outer and inner space, yet many limitations still exist.

Detection

Detection of animal species presence during surveys is often highly imperfect (MacKenzie et al. 2002). Pika detection in lava landscapes is particularly challenging with detection probabilities far lower than in alpine habitats, with probabilities approaching 50% in some areas, particularly highly complex a'a lava (Shinderman 2015). The challenges of basic animal detection are extremely important and perhaps further exacerbated or amplified when detecting, estimating, and identifying actual dispersal distances, timing, and corridors and the connectivity of patches and populations. In animal studies, radio or satellite tracking systems are typically used to understand these dynamics; however, the extreme sensitivity of pikas to temperature and manipulation make it difficult to safely capture and handle them (Wilkening et al. 2013). This, along with their rather cryptic subterranean habitat, make physiological monitoring extremely difficult. Indirect, noninvasive techniques, however, have been tested that could infer the potential impacts of environmental factors on pika fitness (Wilkening et al. 2013).

Identifying connectivity

Scientific understanding of WBP and pikas also faces technological challenges related to the need to better understand genetic and functional connectivity, adaptive capacity, complementary genes or alleles important for genetic conservation, and replicability among populations. This is particularly important for the identification of rust resistance in WBP due to the potential for increased frequency or severity of "wave years" from climate change. The current model of *ex situ* disease resistance breeding programs is extremely time and resource demanding and may be impractical to the management plans or budgets of many managers. Efficient and inexpensive molecular methods (Richardson et al. 2010) for identifying WPBR resistance and other adaptive markers are sorely needed to increase our understanding of genetic diversity and structure across WBP populations.

Competing model confusion

Another critical challenge for both American pika and WBP conservation and management includes the remaining scientific uncertainty and disagreement about competing species-level models of change under future scenarios. Models differ in their complexity, parameterization, underlying assumptions, and levels of uncertainty. It is always essential to remember that "all models are wrong, but some are useful" (Box and Draper 1987). However, interpreting and contrasting complex models that stem from different families of model types and methods can be confusing and overwhelming to researchers and managers alike. There is a need for clear and transparent documentation of similarities and differences among different models of species occupancy and extinction. Modeling efforts for both species would greatly benefit from efforts to create model "genealogies" that help audiences understand discrepancies or wide ranges of estimates being presented and how to interpret this uncertainty arising from both methodological and model differences (Vano et al. 2013). Furthermore, we need general agreement that some models (e.g. occupancy models) are good for some questions while others are better for different questions, even when applied to the same population of study.

Political and social drivers

Values

Successful conservation often involves the values and norms of the public and management communities. Both WBP and pikas are conservation icons of high elevation systems and wilderness. However, the local and regional place-based value that communities have for WBP and pikas and how they may impact management decisions are not clear and likely vary across regions and over time. Value mapping may provide useful insight into the perception of these species and attitudes towards different management actions (Brown 2004; Raymond et al. 2009).

Peril vs. persistence

In an Endangered Species Act era of conservation, there is a focus on extinction and a dominant perception of iconic species in trouble uniformly throughout their range. However, some iconic species have a great capacity for persistence. WBP and pikas are great examples as they have persisted through the tremendous environmental change of interglacial oscillations (Aitken et al. 2008; Anderson 1987; Hafner 1994; Kelly 2014; Mitton et al. 2000; Shriver and Minckley 2012). It is unclear how the public, resource managers, and researchers understand or consider contrasts of persistence versus decline, extirpation, and extinction. This leads us to ask, can we create an opportunity to educate about the complexities of persistence and facilitate adaptation to future change? Can we set or reset public expectations after periods of disturbance to illuminate the role of disturbance in persistence of iconic species? In general, we need to better convey an understanding of science as process rather than product, develop a greater acceptance of uncertainty, and appreciate that time is an extremely important component of ecosystem and species response to specific phenomena, human or otherwise.

Need for indicators

Many sociopolitical factors relate to management challenges. One challenge inherent in dealing with wide ranging species is identifying geographic, landscape level indicators. The similarities that link the Sierra Nevada, Klamath, and Upper Columbia River regions and the factors that make them unique are biogeographically idiosyncratic and highly variable, generating uncertainty and even confusion. Identifying broadly applicable indicators, even though the specifics may be unique to a given site, region, or habitat, is especially relevant to addressing how to deal with single species management constraints versus managing in a landscape context. Each region may deal with this differently, depending on local priorities and mandates of decision makers and the public alike. Local priorities are often uncertain within and among political and management boundaries and can change quickly related to funding, directives, and administration.

Balancing risk

Risk is central to any decision making process and is typically very uncertain when related to issues of climate change. Potential management options often encompass a wide range of risk. Therefore, prioritization of management resources and actions balances risk with reward, often in terms of the likelihood and timing of success. Uncertainty restricts action due to the associated risk. One challenge we face is to present lower risk options that facilitate desired conservation and management goals. For example, one proposed high-risk approach to addressing limited dispersal and extirpation for many species is assisted migration, which has substantial biological, ecological, and social complexities and issues. A low-risk option that may address the same concerns is the creation of corridors to facilitate future migration and increase functional connectivity. This low-risk option also recognizes the value of persistence. Another low-risk alternative is the identification of climate refugia - *areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological, and socio-cultural resources* (Morelli et al. 2016). Climate change refugia can be actively managed for the benefit of local persistence of valued resources which provides time for systems to adapt and managers and society to develop and implement longer-term solutions (Morelli et al. 2016). However, management is often constricted by unpredictable and short-term fiscal year budgets and frequent personnel turnover which limit long-term proactive planning, monitoring, and research. A central challenge to species conservation will be balancing risk, uncertainty, and short- vs. long-term planning in a rapidly changing world. This will require active outreach, education, and conversation between a wide range of stakeholders, including managers, researchers, academia, and the public.

Management in Wilderness

Significant amounts of WBP and American pika habitat are within designated wilderness areas, creating uncertainty surrounding allowable management actions and public perception of them. Almost 50% of potential WBP habitat and existing stands of WBP are located within designated wilderness areas and national parks, particularly within the Cascades and Sierra Nevada regions (Keane 2000; Tomback and Achuff 2010). Management actions, such as outplanting of rust-resistant genotypes, mechanical thinning of encroaching species, and prescribed fire may be viewed as inappropriate by managers or the public for these land designations. For pikas, feasible conservation options, even in protected areas include designation of refugial core areas that are both important habitat centers and have clear dispersal corridors, and, as needed, augmentation of corridors using trail armament specifically as habitat for pikas (Millar et al. 2018). Monitoring over time is especially important for pikas due to their metapopulation behavior (Moilanen et al. 1998; Smith and Nagy 2015). Both agency-specific interpretation of the Wilderness Act for their managed areas and the public perception of wilderness ethics could present hurdles to some proposed management actions, but are poorly understood for most regions. Conservation and management action plans that will include scientific activities in designated wilderness areas will need to plan for agency approvals. The challenges of approval will depend on the activity and the agency. Landscape-scale conservation actions that encompass multiple wilderness areas managed by multiple agencies would benefit from coordinated shared guidelines for activities seen as necessary for species conservation.

Next steps

Our goal is to provide resources that help natural resource managers prioritize actions and assess risk based on the relative uncertainty of how a wide range of drivers may impact two species of conservation concern and the communities and ecosystems they inhabit. Ultimately, the information presented here is aimed at laying a foundation for successive phases of the scenario planning process. Moving forward, we suggest the following next steps:

- Conduct outreach and communication with individual national park personnel within each region to determine when and how scenario planning exercises could meet their management needs.
- Identify other stakeholders that should be included in scenario planning work.
- Work with scenario planning professionals to develop appropriate scenario planning methods and logistics that would meet the needs and budgets of particular parks and regional stakeholders. For example, with limited funding and travel capacity for many federal employees, webinar series can be a useful tool for informing and preparing stakeholders for a scenario planning event.
- For American pika, develop a bibliography of published models of pika persistence and extinction to help clarify current assumptions and hypotheses, guide future research, and develop a baseline for comparison and understanding.
- Explore and further refine key knowledge gaps listed below that could be addressed with targeted monitoring and research, and, once filled, could greatly increase certainty and reduce risk of future management actions.

Key knowledge gaps

While there are many knowledge gaps in the natural history, biology, and ecology of WBP and American pika, some likely have greater bearing on understanding how these species respond to environmental change and our management actions. Below are several gaps that may be particularly helpful in reducing uncertainty and limiting management risk.

Populations

It is important to remember that natural selection occurs within populations. Likewise, biodiversity loss and **extinction occurs through the accumulating extirpation of populations** (Hughes et al. 1997). Much of our knowledge deficit stems from a deficiency of data for most populations of WBP and pikas. Data on local genetic diversity, connectivity and gene flow, adaptation, and plasticity of response to environmental change is greatly lacking for most populations of both species. While there are a few relatively well studied or monitored populations, such as WBP and pikas at Crater Lake National Park, other populations remain unstudied, especially populations outside of park units. This specifically speaks to a general need for long-term monitoring programs for species which may, or may not, be in peril. Because we have relatively long-standing monitoring programs for both focal species, we should continue to invest in them as the primary method to reduce the uncertainties listed throughout this document.

Specifically, we require information on:

- Impacts of variable snowpack and snowmelt timing in subalpine/alpine versus low elevation populations on pikas
  - productivity
  - survival
  - phenological synchrony with food plants
  - population persistence
- Relative contributions of all factors to site persistence/extinction of pika populations across regions, especially subalpine/alpine vs. volcanic-low elevation populations
- The role of non-climatic factors in contributing to pikas population decline versus persistence
- Locations of pika refugia and designing long-term (one the order of centuries to millennia) future population connectivity and resiliency
- Genetic markers of WPBR resistance that are easily and inexpensively assessable
- Relative contribution of factors (e.g., MPB, WPBR, encroachment) to WBP mortality and extirpation in different regional populations
- Local adaptations for WBP and pikas that could benefit or limit management and conservation actions

References

Aitken, S. N., and J. B. Bemmels. 2016. Time to get moving: assisted gene flow of forest trees. Evolutionary Applications 9(1):271-290.

Aitken, S. N., and M. C. Whitlock. 2013. Assisted gene flow to facilitate local adaptation to climate change. Annual Review of Ecology, Evolution, and Systematics 44:367–388. https://doi.org/10.1146/annurev-ecolsys-110512-135747

Aitken, S. N., S. Yeaman, J. A. Holliday, T. Wang, and S. Curtis-McLane. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications 1:95–111. doi:10.1111/j.1752-4571.2007.00013.x

Alder, J. R., and S. W. Hostetler. 2014. Global climate simulations at 3000 year intervals for the last 21 000 years with the GENMOM coupled atmosphere–ocean model. Climate of the Past Discussions 10(4):2925–2978. doi:10.5194/cpd-10-2925-2014

Amberson, J. T. 2013. Effects of disturbance on tree community dynamics in whitebark pine ecosystems. Graduate Student Theses, Dissertations, & Professional Papers. 4224. http://scholarworks.umt.edu/cgi/viewcontent.cgi?article=5247&context=etd

Anderson, R. S. 1987. Late-quaternary environments of the Sierra Nevada, California. PhD Dissertation, University of Arizona. http://arizona.openrepository.com/arizona/handle/10150/184205.

Arno, S. F., and R. J. Hoff. 1989. Silvics of whitebark pine (*Pinus albicaulis*). General Technical Report-Intermountain Research Station, USDA Forest Service, (INT-253). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.574.4438&rep=rep1&type=pdf.

Bardgett, R. D., C. Freeman, and N. J. Ostle. 2008. Microbial contributions to climate change through carbon cycle feedbacks. The ISME Journal 2:805–814. doi:10.1038/ismej.2008.58

Baron, J. S., L. Gunderson, C. D. Allen, E. Fleishman, D. McKenzie, L. A. Meyerson, J. Oropeza, and N. Stephenson. 2009. Options for national parks and reserves for adapting to climate change. Environmental Management 44:1033–1042. doi:10.1007/s00267-009-9296-6

Barry, D., and S. McDonald. 2012. Climate change or climate cycles? Snowpack trends in the Olympic and Cascade Mountains, Washington, USA. Environmental Monitoring and Assessment 185(1):719–728. doi:10.1007/s10661-012-2587-z

Beck, J. S. 2015. Whitebark Pine Conservation Program annual report. Crater Lake National Park, Crater Lake, Oregon. https://www.nps.gov/rlc/craterlake/upload/2015_CRLA_WPCP_-Annual-Report.pdf.

Beever, E. A., S. Dubrowski, J. Long, A. Mysnberge, and N. B. Piekielek. 2014. Understanding relationships among abundance, extirpation, and climate at ecoregional scales. Ecology 94:9.

Beever, E. A., C. Ray, J. L. Wilkening, P. F. Brussard, and P. W. Mote. 2011. Contemporary climate change alters the pace and drivers of extinction. Global Change Biology 17:2054–2070. doi:10.1111/j.1365-2486.2010.02389.x

Bentz, B. J., S. Kegley, K. Gibson, and R. Thier. 2005. A test of high-dose verbenone for stand-level protection of lodgepole and whitebark pine from mountain pine beetle (Coleoptera: Curculionidae: Scolytinae) attacks. Journal of Economic Entomology 98:1614–1621.

Biggins, D. E., and M. Y. Kosoy. 2001. Influences of introduced plague on North American mammals: Implications from ecology of plague in Asia. Journal of Mammalogy 82:906–916. https://doi.org/10.1644/1545-1542(2001)082<0906:IOIPON>2.0.CO;2

Bower, A. D., and S. N. Aitken. 2006. Geographic and seasonal variation in cold hardiness of whitebark pine. Canadian Journal of Forest Research 36:1842–1850. doi:10.1139/x06-067

Bower, A. D., and S. N. Aitken. 2007. Mating system and inbreeding depression in whitebark pine (*Pinus albicaulis* Engelm.). Tree Genetics & Genomes 3:379–388. doi:10.1007/s11295-007-0082-4

Bower, A. D., and S. N. Aitken. 2008. Ecological genetics and seed transfer guidelines for *Pinus albicaulis* (Pinaceae). American Journal of Botany 95:66–76. doi:10.3732/ajb.95.1.66

Bower, A. D., S. C. McLane, A. Eckert, S. Jorgensen, A. Schoettle, and S. Aitken. 2011. Conservation genetics of high elevation five-needle white pines. Pages 98-117 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Bower, A. D., B. A. Richardson, V. Hipkins, R. Rochefort, and C. Aubry. 2011. Comparison of genetic diversity and population structure of Pacific Coast whitebark pine across multiple markers. Pages 28-30 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Box, G. E., and N. R. Draper. 1987. Empirical model-building and response surfaces. Wiley, New York.

Brar, S., C. K. M. Tsui, B. Dhillon, M.-J. Bergeron, D. L. Joly, P. J. Zambino, Y. A. El-Kassaby, and R. C. Hamelin. 2015. Colonization history, host distribution, anthropogenic influence and landscape features shape populations of white pine blister rust, an invasive alien tree pathogen. PLoS ONE 10:e0127916. doi:10.1371/journal.pone.0127916

Brown, G. 2004. Mapping spatial attributes in survey research for natural resource management: methods and applications. Society & Natural Resources 18:17–39. doi:10.1080/08941920590881853

Burns, C. E., K. M. Johnston, and O. J. Schmitz. 2003. Global climate change and mammalian species diversity in U.S. national parks. Proceedings of the National Academy of Sciences 100:11474–11477. doi:10.1073/pnas.1635115100

Castillo, J. A., C. W. Epps, A. R. Davis, and S. A. Cushman. 2014. Landscape effects on gene flow for a climate-sensitive montane species, the American pikas. Molecular Ecology 23:843–856. doi:10.1111/mec.12650

Castillo, J. A., C. W. Epps, M. R. Jeffress, C. Ray, T. J. Rodhouse, and D. Schwalm. 2016. Replicated landscape genetic and network analyses reveal wide variation in functional connectivity for American pikas. Ecological Applications 26: 1660-1676. DOI: 10.1890/15-1452.1

Clason, A. J., S. E. Macdonald, and S. Haeussler. 2014. Forest response to cumulative disturbance and stress: two decades of change in whitebark pine ecosystems of west-central British Columbia. Ecoscience 21:174–185. doi:10.2980/21-2-3686

Collins, G. H. and B. T. Bauman. 2012. Distribution of low-elevation American pika populations in the northern Great Basin. Journal of Fish and Wildlife Management 3:311. https://doi.org/10.3996/042012-JFWM-032

Coop, J. D., and A. W. Schoettle. 2011. Fire and high-elevation, five-needle pine (*Pinus aristata* & *P. flexilis*) ecosystems in the southern Rocky Mountains: What do we know? Pages 164-173 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

David, S. T., S. Mak, L. MacDougall, and M. Fyfe. 2007. A bird's eye view: Using geographic analysis to evaluate the representativeness of corvid indicators for West Nile virus surveillance. International Journal of Health Geographics 6:3. doi:10.1186/1476-072X-6-3

Dawson, T. P., S. T. Jackson, J. I. House, I. C. Prentice, and G. M. Mace. 2011. Beyond predictions: Biodiversity conservation in a changing climate. Science 332:53–58. doi:10.1126/science.1200303

Dayton, P. K. 1972. Toward an understanding of community resilience and the potential effects of enrichments to the benthos at McMurdo Sound, Antarctica. Pages 81–95 *in* Proceedings of the Colloquium on Conservation Problems in Antarctica. Allen Press, Lawrence, Kansas.

Dearing, M. D. 1995. Factors governing diet selection in a herbivorous mammal, the North American pikas (*Ochotona princeps*). Doctoral dissertation, PhD Dissertation, University of Utah, Salt Lake City, Utah.

Dennison, P. E., S. C. Brewer, J. D. Arnold, and M. A. Moritz. 2014. Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters 41:2928-2933. doi:10.1002/2014GL059576

Dull, R.A., 1999. Palynological evidence for 19th century grazing-induced vegetation change in the southern Sierra Nevada, California, USA. *Journal of Biogeography* 26(4):899-912.

Eckert, A. J., B. R. Tearse, and B. D. Hall. 2008. A phylogeographical analysis of the range disjunction for foxtail pine (*Pinus balfouriana*, Pinaceae): the role of Pleistocene glaciation. Molecular Ecology 17:1983–1997.

Ellison, A. M., M. S. Bank, B. D. Clinton, E. A. Colburn, K. Elliott, C. R. Ford, D. R. Foster, B. D. Kloeppel, J. D. Knoepp, G. M. Lovett, and others. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3:479–486.

Falcy, M. 2016. Conservation decision making: integrating the precautionary principle with uncertainty. Frontiers in Ecology and the Environment 14:499–504. doi:10.1002/fee.1423

Farnes, P. E. 1990. SNOTEL and snow course data: describing the hydrology of whitebark pine ecosystems. Pages 302-304 *in* W. C. Schmidt, and K. J. McDonald, editors. Proceedings—Symposium on whitebark pine ecosystems: Ecology and management of a high-mountain resource. General Technical Report INT-270. Intermountain Research Station, USDA Forest Service, Ogden, Utah.

Fisher, M. C., D. A. Henk, C. J. Briggs, J. S. Brownstein, L. C. Madoff, S. L. McCraw, and S. J. Gurr. 2012. Emerging fungal threats to animal, plant and ecosystem health. Nature 484. doi:10.1038/nature10947

Frankham, R. 2005. Genetics and extinction. Biological Conservation 126:131–140. doi:10.1016/j.biocon.2005.05.002

Galbreath, K. E., D. J. Hafner, and K. R. Zamudio. 2009. When cold is better: Climate-driven elevation shifts yield complex patterns of diversification and demography in an alpine specialist (American pikas, *Ochotona princeps*). Evolution [International Journal of Organic Evolution] 63:2848–2863. doi:10.1111/j.1558-5646.2009.00803.x

Galdan, B., U. Baatar, B. Molotov, and O. Dashdavaa. 2010. Plague in Mongolia. Vector-Borne and Zoonotic Diseases 10:69–75. https://doi.org/10.1089/vbz.2009.0047

Gardes, M., and T. D. Bruns. 1996. Community structure of ectomycorrhizal fungi in a *Pinus muricata* forest: Above- and below-ground views. Canadian Journal of Botany 74:1572–1583. https://doi.org/10.1139/b96-190

Geils, B.W., and D. R. Vogler. 2011. A natural history of *Cronartium ribicola*. Pages 210-217 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Goeking, S. A., and D. K. Izlar. 2018. *Pinus albicaulis* Engelm. (Whitebark Pine) in mixed-species stands throughout its US Range: Broad-scale indicators of extent and recent decline. Forests 9(3): 131. https://doi.org/10.3390/f9030131

Grayson, D. K. 2005. A brief history of Great Basin pikas. Journal of Biogeography 32:2103–2111. https://doi.org/10.1111/j.1365-2699.2005.01341.x

Hafner, D. J. 1993. North American pikas (*Ochotona princeps*) as a Late Quaternary biogeographic indicator species. Quaternary Research 39:373–380.

Hafner, D. J. 1994. Pikas and permafrost: Post-Wisconsin historical zoogeography of *Ochotona* in the Southern Rocky Mountains, U.S.A. Arctic, Antarctic, and Alpine Research 26:375–382. doi:10.2307/1551799

Hafner, D. J., and A. T. Smith. 2010. Revision of the subspecies of the American pikas, *Ochotona princeps* (Lagomorpha: Ochotonidae). Journal of Mammalogy 91:401–417. doi:10.1644/09-MAMM-A-277.1

Hamelin, R. C., M. Allaire, M. -J. Bergeron, M. -C. Nicole, and N. Lecours. 2005. Molecular epidemiology of white pine blister rust: Recombination and spatial distribution. Phytopathology 95:793–799. doi:10.1094/PHYTO-95-0793

Hamelin, R. C., R. S. Hunt, B. W. Geils, G. D. Jensen, V. Jacobi, and N. Lecours. 2000. Barrier to gene flow between eastern and western populations of *Cronartium ribicola* in North America. Phytopathology 90:1073–1078. doi:10.1094/PHYTO.2000.90.10.1073

Hamlin, J., A. Kegley, and R. Sniezko. 2011. Genetic variation of whitebark pine (*Pinus albicaulis*) provenances and families from Oregon and Washington in juvenile height growth and needle color. Pages 133-139 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Henry, P., and M. A. Russello. 2013. Adaptive divergence along environmental gradients in a climate-change-sensitive mammal. Ecological Evolution 3:3906–3917. doi:10.1002/ece3.776

Henry, P., Z. Sim, and M. A. Russello. 2012. Genetic evidence for restricted dispersal along continuous altitudinal gradients in a climate change-sensitive mammal: the American pikas. PLOS ONE 7:e39077. doi:10.1371/journal.pone.0039077

Hobbs, R.P. 1980. Interspecific interactions among gastrointestinal helminths in pikas of North America. American Midland Naturalist 103:15–25. https://doi.org/10.2307/2425034

Hoff, R. J., D. E. Ferguson, G. I. McDonald, and R. E. Keane. 2001. Strategies for managing whitebark pine in the presence of white pine blister rust. Pages 346–366 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Hofstetter, R. W., J. Dinkins-Bookwalter, T. S. Davis, and K. D. Klepzig. 2015. Symbiotic associations of bark beetles. Pages 209–245 *in* F. E. Vega, and R. W. Hofstetter, editors, Bark beetles, biology and ecology of native and invasive species. Academic Press, Elsevier Inc, San Diego, California.

Hughes, J. B., G. C. Daily, and P. R. Ehrlich. 1997. Population diversity: Its extent and extinction. Science 278:689–692. doi:10.1126/science.278.5338.689

Huntley, B. 1991. How plants respond to climate change: Migration rates, individualism and the consequences for plant communities. Annals of Botany 67:15–22.

Iglesias, V., T. R. Krause, and C. Whitlock. 2015. Complex response of white pines to past environmental variability increases understanding of future vulnerability. PLoS ONE 10:e0124439. doi:10.1371/journal.pone.0124439

IPCC 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (editors)]. IPCC, Geneva, Switzerland, 151 pp.

IUCN (International Union for Conservation of Nature) 2016. *Ochotona princeps*. The IUCN Red List of Threatened Species. Version 2017-3. http://maps.iucnredlist.org/map.html?id=41267

Jeffress, M. R., T. J. Rodhouse, C. Ray, S. Wolff, and C. W. Epps. 2013. The idiosyncrasies of place: geographic variation in the climate-distribution relationships of the American pikas. Ecological Applications 23:864–878.

Jenkins, M. J. 2011. Fuel and fire behavior in high-elevation five-needle pines affected by mountain pine beetle. Pages 190-197 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Jorgensen, S. M., and J. L. Hamrick. 1997. Biogeography and population genetics of whitebark pine, *Pinus albicaulis*. Canadian Journal of Forest Research 27:1574–1585. doi:10.1139/x97-118

Jules, E. S., J. I. Jackson, P. J. van Mantgem, J. S. Beck, M. P. Murray, and E. A. Sahara. 2016. The relative contributions of disease and insects in the decline of a long-lived tree: A stochastic demographic model of whitebark pine (*Pinus albicaulis*). Forest Ecology and Management 381:144–156. doi:10.1016/j.foreco.2016.09.022

Keane, R. E. 2000. The importance of wilderness to whitebark pine research and management. In Proceedings of the symposium: Wilderness Science: In a time for change. Vol. 3, pp. 84-93.

Keane, R., and R. Loehman. 2010. Understanding the role of wildland fire, insects, and disease in predicting climate change effects on whitebark pine: Simulating vegetation, disturbance, and climate dynamics in a northern Rocky Mountain landscape. American Geophysical Union. Fall Meeting: Abstract #NH33B-06.

Keane, R. E., and R. A. Parsons. 2010. Management guide to ecosystem restoration treatments: Whitebark pine forests of the northern Rocky Mountains, U.S.A. Gen. Tech. Rep. RMRS-GTR-232. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 133 p.

Keane, R. E., D. F. Tomback, C. A. Aubry, A. D. Bower, E. M. Campbell, C. L. Cripps, M. B. Jenkins, M. F. Mahalovich, M. Manning, S. T. McKinney, M. P. Murray, D. L. Perkins, D. P. Reinhart, C. Ryan, A. W. Schoettle, and C. M. Smith. 2012. A range-wide restoration strategy for whitebark pine (*Pinus albicaulis*). Gen. Tech. Rep. RMRS-GTR-279. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 108 p.

Keane, R. E., L. M. Holsinger, M. F. Mahalovich, and D. F. Tomback. 2017. Restoring whitebark pine ecosystems in the face of climate change. Gen. Tech. Rep. RMRS-GTR-361. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 123 p.

Kelly, K. E. 2014. Paleoecological reconstruction of a modern whitebark pine (*Pinus albicaulis*) population in Grand Teton National Park, WY. Thesis. Kansas State University, Manhattan, Kansas.

King, J. N., A. David, D. Noshad, and J. Smith. 2010. A review of genetic approaches to the management of blister rust in white pines. Forest Pathology 40:292–313. doi:10.1111/j.1439-0329.2010.00659.x

Kinloch, B. B. 2003. White pine blister rust in North America: Past and prognosis. Phytopathology 93:1044–1047. doi:10.1094/PHYTO.2003.93.8.1044

Kinloch, B. B., R. A. Sniezko, and G. E. Dupper. 2004. Virulence gene distribution and dynamics of the white pine blister rust pathogen in western North America. Phytopathology 94:751–758. doi:10.1094/PHYTO.2004.94.7.751

Kinloch, J., B. Bohun, R. D. Westfall, E. E. White, M. A. Gitzendanner, G. E. Dupper, B. M. Foord, and P. D. Hodgskiss. 1998. Genetics of *Cronartium ribicola*. IV. Population structure in western North America. Canadian Journal of Botany 76:91–98. doi:10.1139/b97-167

Kinloch Jr., B. B., and G. E. Dupper. 1987. Restricted distribution of a virulent race of the white pine blister rust pathogen in the western United States. Canadian Journal of Forest Research 17: 448–451. doi:10.1139/x87-077

Kipfmeuller, K. F. 2003. Fire-climate-vegetation interactions in subalpine forests of the Selway-Bitterroot Wilderness Area, Idaho and Montana, United States. Thesis. University of Arizona, Tucson, Arizona.

Komar, N. 2003. West Nile virus: Epidemiology and ecology in North America. Advances in Virus Research 61: 185-234.

Krakowski, J. 2001. Conservation genetics of whitebark pine (*Pinus albicaulis* Engelm) in British Columbia. Thesis. Unviersity of British Columbia, Vancouver, BC, Canada.

Krakowski, J., S. N. Aitken, and Y. A. El-Kassaby. 2003. Inbreeding and conservation genetics in whitebark pine. Conservation Genetics 4:581–593. doi:10.1023/A:1025667700479

Kriebel, D., J. Tickner, P. Epstein, J. Lemons, R. Levins, E. L. Loechler, M. Quinn, R. Rudel, T. Schettler, and M. Stoto. 2001. The precautionary principle in environmental science. Environmental Health Perspectives 109(9): 871-876.

Kunkel, K. E., T. R. Karl, D. R. Easterling, K. Redmond, J. Young, X. Yin and P. Hennon. 2013. Probable maximum precipitation and climate change. Geophysical Research Letters 40:1402-1408. Doi: 10.1002/grl.50334

LaDeau, S. L., A. M. Kilpatrick, and P. P. Marra. 2007. West Nile virus emergence and large-scale declines of North American bird populations. Nature 447:710.

Lanner, R. M., and S. B. Vander Wall. 1980. Dispersal of limber pine seed by Clark's nutcracker. Journal of Forestry 78:637–639.

Lawler, J. J., T. H. Tear, C. Pyke, M. R. Shaw, P. Gonzalez, P. Kareiva, L. Hansen, L. Hannah, K. Klausmeyer, A. Aldous, C. Bienz, and S. Pearsall. 2008. Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment 8:35–43. doi:10.1890/070146

Linhart, Y. B., and D. F. Tomback. 1985. Seed dispersal by nutcrackers causes multi-trunk growth form in pines. Oecologia 67:107–110.

Little, Elbert L., Jr. 1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. Miscellaneous Publication 1146. Washington, DC: U.S. Department of Agriculture, Forest Service. 9 p., illus. [313 maps, folio]. https://www.arcgis.com/home/item.html?id=aa43fa61af68431099ea5353814e4bf5

MacKenzie, D.I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255. https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

Mahalovich, M. F., K. E. Burr, and D. L. Foushee. 2006. Whitebark pine germination, rust resistance, and cold hardiness among seed sources in the Inland Northwest: Planting strategies for restoration. USDA forest service proceedings RMRS-P-43, 91-101.

Mahalovich, M. F., and V. D. Hipkins. 2011. Molecular genetic variation in whitebark pine (*Pinus albicaulis* Engelm.) in the Inland West. Pages 118-132 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Manning, T., and J. C. Hagar. 2011. Use of non-alpine anthropogenic habitats by American pikas (*Ochotona princeps*) in western Oregon, USA. Western North American Naturalist 71:106112. https://doi.org/10.3398/064.071.0114

Manning, W. J., and A. v. Tiedemann. 1995. Climate change: Potential effects of increased atmospheric Carbon dioxide (CO2), ozone (O3), and ultraviolet-B (UV-B) radiation on plant diseases. Environmental Pollution 88:219–245. doi:10.1016/0269-7491(95)91446-R

McDonald, G., P. Zambino, and R. Sniezko. 2004. Breeding rust-resistant five-needle pines in the western United States: lessons from the past and a look to the future. Pages 45-50 *in* R. A. Sniezko, S. Samman, S. E. Schlarbaum, and H. B. Kriebel, editors. Breeding and genetic resources of five-needle pines: Growth, adaptability and pest resistance; 2001 July 23–27; Medford, OR, USA. IUFRO Working Party 2.02.15. Proceedings RMRS-P-32. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

McDonald, G. I.; R. J. Hoff, and W. R. Wykoff. 1981. Computer simulation of white pine blister rust epidemics. I. Model formulation. Res. Pap. INT-RP-258. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 136 p.

McLane, S. C., and S. N. Aitken. 2012. Whitebark pine (*Pinus albicaulis*) assisted migration potential: Testing establishment north of the species range. Ecological Applications 22:142–153.

Mielke, J. L. 1943. White pine blister rust in western North America. PhD Dissertation. Yale Univ.

Millar, C. I. 2011. Influence of domestic livestock grazing on American pika (*Ochotona princeps*) haypiling behavior in the Eastern Sierra Nevada and Great Basin. Western North American Naturalist 71(3):425–430. https://doi.org/10.3398/064.071.0311

Millar, C. I., D. L. Delany, K. A. Hersey, M. R. Jeffress, A. T. Smith, K. J. V. Gunst, and R. D. Westfall. 2018. Distribution, climatic relationships, and status of American pikas (*Ochotona* *princeps*) in the Great Basin, USA. Arctic, Antarctic, and Alpine Research 50. e1436296. https://doi.org/10.1080/15230430.2018.1436296

Millar, C. I., K. Heckman, C. Swanston, K. Schmidt, R. D. Westfall, and D. L. Delany. 2014. Radiocarbon dating of American pika fecal pellets provides insights into population extirpations and climate refugia. Ecological Applications 24:1748-68.

Millar, C. I., and R. D. Westfall. 2010. Distribution and climatic relationships of the American pikas (*Ochotona princeps*) in the Sierra Nevada and Western Great Basin, U.S.A.; Periglacial landforms as refugia in warming climates. Arctic, Antarctic, and Alpine Research 42:76–88. doi:10.1657/1938-4246-42.1.76

Millar, C. I., R. D. Westfall, and D. L. Delany. 2007. Response of high-elevation limber pine (*Pinus flexilis*) to multiyear droughts and 20th-century warming, Sierra Nevada, California, USA. Canadian Journal of Forest Research 37:2508–2520.

Millar, C. I., R. D. Westfall, and D. L. Delany. 2014. Thermal regimes and snowpack relations of periglacial talus slopes, Sierra Nevada, California, U.S.A. Arctic, Antarctic, and Alpine Research 46:483–504. doi:10.1657/1938-4246-46.2.483

Millar, C. I., R. D. Westfall, and D. L. Delany. 2016. Thermal components of American pika habitat-How does a small lagomorph encounter climate? Arctic, Antarctic, and Alpine Research 48: 327–343.

Millar, C. I., R. D. Westfall, D. L. Delany, M. J. Bokach, A. L. Flint, and L. E. Flint. 2012. Forest mortality in high-elevation whitebark pine (*Pinus albicaulis*) forests of eastern California, USA; influence of environmental context, bark beetles, climatic water deficit, and warming. Canadian Journal of Forest Research 42:749–765.

Millar, C. I., R. D. Westfall, D. L. Delany, A. L. Flint, and L. E. Flint. 2015. Recruitment patterns and growth of high-elevation pines in response to climatic variability (1883–2013), in the western Great Basin, USA. Canadian Journal of Forest Research 45:1299–1312.

Millar, C. I., R. D. Westfall, A. Evenden, J. G. Holmquist, J. Schmidt-Gengenbach, R. S. Franklin, J. Nachlinger, and D. L. Delany. 2015. Potential climatic refugia in semi-arid, temperate mountains: Plant and arthropod assemblages associated with rock glaciers, talus slopes, and their forefield wetlands, Sierra Nevada, California, USA. Quaternary International 387:106–121.

Miraldo, A., S. Li, M. K. Borregaard, A. Flórez-Rodríguez, S. Gopalakrishnan, M. Rizvanovic, Z. Wang, C. Rahbek, K. A. Marske, and D. Nogués-Bravo. 2016. An Anthropocene map of genetic diversity. Science 353:1532–1535. doi:10.1126/science.aaf4381

Mitton, J. B., B. R. Kreiser, and R. G. Latta. 2000. Glacial refugia of limber pine (*Pinus flexilis* James) inferred from the population structure of mitochondrial DNA. Molecular Ecology 9:91–97.

Mohatt, K. R. 2006. Ectomycorrhizal fungi of whitebark pine (*Pinus albicaulis*) in the Northern Greater Yellowstone Ecosystem. (Thesis). Montana State University - Bozeman, College of Agriculture.

Moilanen, A., I. Hanski, and A. T. Smith. 1998. Long-term dynamics in a metapopulation of the American pika. American Naturalist 152:530–542.

Monahan, W. B., and N. A. Fisichelli. 2014. Climate exposure of US National Parks in a new era of change. PLoS ONE 9 e101302. doi:10.1371/journal.pone.0101302

Morelli, T. L., C. Daly, S. Z. Dobrowski, D. M. Dulen, J. L. Ebersole, S. T. Jackson, J. D. Lundquist, C. I. Millar, S. P. Maher, W. B. Monahan, K. R. Nydick, K. T. Redmond, S. C. Sawyer, S. Stock, and S. R. Beissinger. 2016. Managing climate change refugia for climate adaptation. PLOS ONE 11, e0159909. https://doi.org/10.1371/journal.pone.0159909

Morello-Frosch, R., M. Pastor Jr, and J. Sadd. 2002. Integrating environmental justice and the precautionary principle in research and policy making: The case of ambient air toxics exposures and health risks among schoolchildren in Los Angeles. The ANNALS of the American Academy of Political and Social Science 584:47-68.

Moritz, C., J. L. Patton, C. J. Conroy, J. L. Parra, G. C. White, and S. R. Beissinger. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322:261–264. doi:10.1126/science.1163428

Mote, P. W. 2006. Climate-driven variability and trends in mountain snowpack in western North America. Journal of Climate 19:6209–6220. doi:10.1175/JCLI3971.1

Pepin, N., R. S. Bradley, H. F. Diaz, M. Baraer, E. B. Caceres. N. Forsyth, H. Fowler, and others. 2015. Elevation-dependent warming in mountain regions of the world. Nature Climate Change 5:424–430.

Muhlfeld, C. C., J. J. Giersch, F. R. Hauer, G. T. Pederson, G. Luikart, D. P. Peterson, C. C. Downs, and D. B. Fagre. 2011. Climate change links fate of glaciers and an endemic alpine invertebrate. Climate Change 106:337–345. doi:10.1007/s10584-011-0057-1

Nadeau, S., P. G. Meirmans, S. N. Aitken, K. Ritland, and N. Isabel. 2016. The challenge of separating signatures of local adaptation from those of isolation by distance and colonization history: The case of two white pines. Ecology and Evolution 6: 8649-8664. doi.org/10.1002/ece3.2550

National Resource Council. 2010. America's climate choices: Adapting to the impacts of climate change [WWW Document]. GlobalChange.gov. http://www.globalchange.gov/browse/reports/nrc-adapting-impacts-climate-change-americas-climate-choices-report-panel-adapting (accessed 9.24.15).

Nesmith, J. C. B., M. Wright, E. S. Jules, and S. T. McKinney. 2019. Whitebark and foxtail pine in Yosemite, Sequoia, and Kings Canyon National Parks: Initial assessment of stand structure and condition. Forests 2019, 10(1):35. DOI:10.3390/f10010035

Niu, Y., F. Wei, M. Li, X. Liu, and Z. Feng. 2004. Phylogeny of pikas (Lagomorpha, *Ochotona*) inferred from mitochondrial cytochrome b sequences. Folia Zoologica 53:141.

Nolin, A. W. 2012. Perspectives on climate change, mountain hydrology, and water resources in the Oregon Cascades, USA. Mountain Research and Development 32(S1):S35–S46. doi:10.1659/MRD-JOURNAL-D-11-00038.S1

Parks, S. A., C. Miller, J. T. Abatzoglou, L. M. Holsinger, M. A. Parisien, and S. Z. Dobrowski. 2016. How will climate change affect wildland fire severity in the western US? Environmental Research Letters 11(3):035002.

Peacock, M. M. 1997. Determining natal dispersal patterns in a population of North American pikas (*Ochotona princeps*) using direct mark-resight and indirect genetic methods. Behavioral Ecology 8:340–350.

Peacock, M. M., and C. Ray. 2001. Dispersal in pikas (*Ochotona princeps*): Combining genetic and demographic approaches to reveal spatial and temporal patterns. Pages 43–56 *in* J. Clobert, E. Danchin, A. A. Dhondt, and J. D. Nichels, editors. Dispersal: Causes, consequences and mechanisms of dispersal at the individual, population and community level. Oxford University Press, Oxford, United Kingdom.

Pech, R. P., A. D. Arthur, Z. Yanming, and L. Hui. 2007. Population dynamics and responses to management of plateau pikas *Ochotona curzoniae*. Journal of Applied Ecology 44:615–624. https://doi.org/10.1111/j.1365-2664.2007.01287.x

Pederson, G. T., S. T. Gray, C. A. Woodhouse, J. L. Betancourt, D. B. Fagre, J. S. Littell, E. Watson, B. H. Luckman, and L. J. Graumlich. 2011. The unusual nature of recent snowpack declines in the North American Cordillera. Science 333:332–335. doi:10.1126/science.1201570

Pepin, N., R. S. Bradley, H. F. Diaz, M. Baraër, E. B. Caceres, N. Forsythe, H. Fowler, G. Greenwood, M. Z. Hashmi, X. D. Liu, J. R. Miller, and others. 2015. Elevation-dependent warming in mountain regions of the world. Nature Climate Change 5: 424.

Perkins, D. L., and T. W. Swetnam. 1996. A dendroecological assessment of whitebark pine in the Sawtooth-Salmon River region, Idaho. Canadian Journal of Forest Research 26:2123–2133.

Rango, A., and V. F. van Katwijk. 1990. Climate change effects on the snowmelt hydrology of western North American mountain basins. IEEE Transactions on Geoscience and Remote Sensing 28:970–974. doi:10.1109/36.58987

Ray, C., and E. Beever. 2007. Distribution and abundance of the American pika (*Ochotona princeps*) within Lava Beds National Monument. U.S. National Park Service, Unpublished Report.

Ray, C., E. A. Beever, and T. J. Rodhouse. 2016. Distribution of a climate-sensitive species at an interior range margin. Ecosphere 7.

Raymond, C. M., B. A. Bryan, D. H. MacDonald, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2009. Mapping community values for natural capital and ecosystem services. Ecological Economics 68:1301–1315. doi:10.1016/j.ecolecon.2008.12.006

Reisen, W. K., C. M. Barker, R. Carney, H. D. Lothrop, S. S. Wheeler, J. L. Wilson, M. B. Madon, R. Takahashi, B. Carroll, S. Garcia, and others. 2006. Role of corvids in epidemiology of West Nile virus in southern California. Journal of Medical Entomology 43:356–367.

Richardson, B. A., S. J. Brunsfeld, and N. B. Klopfenstein. 2002. DNA from bird-dispersed seed and wind-disseminated pollen provides insights into postglacial colonization and population genetic structure of whitebark pine (*Pinus albicaulis*). Molecular Ecology 11:215–227.

Richardson, B. A., A. K. M. Ekramoddoulah, J.-J. Liu, M.-S. Kim, and N. B. Klopfenstein. 2010. Current and future molecular approaches to investigate the white pine blister rust pathosystem. Forest Pathology 40:314–331. doi:10.1111/j.1439-0329.2010.00660.x

Richardson, B. A., N. B. Klopfenstein, and S. J. Brunsfeld. 2002. Assessing Clark’s nutcracker seed-caching flights using maternally inherited mitochondrial DNA of whitebark pine. Canadian Journal of Forest Research 32:1103–1107.

Rodhouse, T. J., E. A. Beever, L. K. Garrett, K. M. Irvine, M. R. Jeffress, M. Munts, and C. Ray. 2010. Distribution of American pikas in a low-elevation lava landscape: Conservation implications from the range periphery. Journal of Mammalogy 91:1287–1299. doi:10.1644/09-MAMM-A-334.1

Rogers, D. L., C. I. Millar, and R. D. Westfall, R.D. 1999. Fine-scale genetic structure of whitebark pine (*Pinus albicaulis*): Associations with watershed and growth form. Evolution 53: 74–90.

Rose, M., and J. Star. 2013. Using scenarios to explore climate change: A handbook for practitioners. National Park Service, Department of Interior.

Rowe, K. C., K. M. C. Rowe, M. W. Tingley, M. S. Koo, J. L. Patton, C. J. Conroy, J. D. Perrine, S. R. Beissinger, and C. Moritz. 2015. Spatially heterogeneous impact of climate change on small mammals of montane California. Proceedings of the Royal Society B Biological Sciences 282:20141857. https://doi.org/10.1098/rspb.2014.1857

Rowland, E. R., M. S. Cross, and H. Hartmann. 2014. Considering multiple futures: Scenario planning to address uncertainty in natural resource conservation. U.S. Fish and Wildlife Service, Washington, DC. https://www.fws.gov/home/climatechange/pdf/Scenario-Planning-Report.pdf

Schoennagel, T., J. K. Balch, H. Brenkert-Smith, P. E. Dennison, B. J. Harvey, M. A. Krawchuk, N. Mietkiewicz, P. Morgan, M. A. Moritz, R. Rasker, M. G. Turner, and C. Whitlock. 2017. Adapt to more wildfire in western North American forests as climate changes. Proceedings of the National Academy of the Sciences114(18):4582-4590.

Schoettle, A. W. 2004. Developing proactive management options to sustain bristlecone and limber pine ecosystems in the presence of a non-native pathogen. Pages 146–155 *in* Silviculture in Special Places: Proceeding of the National Silviculture Workshop. Proceedings RMRS-P-34, US Department of Agriculture, Rocky Mountain Research Station, Fort Collins, Colorado.

Schoettle, A.W., and R. A. Sniezko. 2007. Proactive intervention to sustain high-elevation pine ecosystems threatened by white pine blister rust. Journal of Forest Research 12:327–336.

Severaid, J. H. 1955. Natural history of the pikas (Mammalian genus *Ochotona*). PhD Dissertation. University of California, Berkeley, California.

Shinderman, M. 2015. American pika in a low-elevation lava landscape: Expanding the known distribution of a temperature-sensitive species. Ecology and Evolution 5(17):3666–3676. https://doi.org/10.1002/ece3.1626

Shriver, R. K., and T. A. Minckley. 2012. Late-Holocene response of limber pine (*Pinus flexilis*) forests to fire disturbance in the Pine Forest Range, Nevada, USA. Quaternary Research 78:465–473.

Simpson, W. G. 2009. American pikas inhabit low-elevation sites outside the species' previously described bioclimatic envelope. Western North American Naturalist 69:243–250. doi:10.3398/064.069.0213

Smith, A. T. 1974. The distribution and dispersal of pikas: Influences of behavior and climate. Ecology 55:1368–1376. doi:10.2307/1935464

Smith, A. T. 1980. Temporal changes in insular populations of the pikas (*Ochotona princeps*). Ecology 61:8–13. doi:10.2307/1937147

Smith, A. T. 1987. Population structure of pikas: Dispersal versus philopatry. Pages 128–142 in B. D. Chepko-Sade and Z. T. Halpin, editors. Mammalian dispersal patterns: The effects of social structure on population genetics. University of Chicago Press, Chicago, Illinois.

Smith, A.T., and C. I. Millar. 2018. American pika (*Ochotona princeps*) population survival in winters with low or no snowpack. Western North American Naturalist 78:126–132. https://doi.org/10.3398/064.078.0203

Smith, A.T., and J. D. Nagy. 2015. Population resilience in an American pika (*Ochotona princeps*) metapopulation. Journal of Mammalogy 96:394–404. https://doi.org/10.1093/jmammal/gyv040

Smith, A. T., and M. L. Weston. 1990. *Ochotona princeps*. Mammalian Species 1–8.

Smithers, B., and B. V. Smithers. 2017. Soil preferences in germination and survival of limber pine in the Great Basin White Mountains. Forests 8:423. https://doi.org/10.3390/f8110423

R. A., A. Kegley, R. Danchok, J. Hamlin, J. Hill, and D. Conklin. 2011. Rust resistance in seedling families of *Pinus albicaulis* and *Pinus strobiformis* and implications for restoration. Page 273 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Sniezko, R. A., M. F. Mahalovich, A. W. Schoettle, and D. R. Vogler. 2011. Past and current investigations of the genetic resistance to *Cronartium ribicola* in high-elevation five-needle pines. Pages 246-264 *in* R. E. Keane, D. F. Tomback, M. P. Murray; and C. M. Smith, editors. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, MT. Proceedings RMRS-P-63. Rocky Mountain Research Station, USDA Forest Service, Fort Collins, Colorado.

Sniezko, R. A., S. Samman, S. E. Schlarbaum, and H. B. Kriebel. 2004. Breeding and genetic resources of five-needle pines: Growth, adaptability, and pest resistance. Proceedings RMRS-P-32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 259 p.

Spaulding, P. 1911. The blister rust of white pine. US Government Printing Office, Washington, DC.

Spielman, D., B. W. Brook, and R. Frankham. 2004. Most species are not driven to extinction before genetic factors impact them. Proceedings of the National Academy of Sciences 101:15261–15264. doi:10.1073/pnas.0403809101

Steel, Z. L., H. D. Safford, and J. H. Viers. 2015. The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere 6:1–23. doi:10.1890/ES14-00224.1

Stewart, J. A. E., J. D. Perrine, L. B. Nichols, J. H. Thorne, C. I. Millar, K. E. Goehring, C. P. Massing, D. H. Wright, and B. Riddle. 2015. Revisiting the past to foretell the future: Summer temperature and habitat area predict pikas extirpations in California. Journal of Biogeography 42:880–890.

Taylor, A. F. S., and I. Alexander. 2005. The ectomycorrhizal symbiosis: Life in the real world. Mycologist 19:102–112. doi:10.1017/S0269915X05003034

TNC, 2007. Conservation Action Planning Handbook: Developing Strategies, Taking Action and Measuring Success at Any Scale. The Nature Conservancy.

Tomback, D. 1982. Dispersal of whitebark pine seeds by Clark's nutcracker: A mutualism hypothesis. Journal of Animal Ecology 51:451–467.

Tomback, D. F., and P. Achuff. 2010. Blister rust and western forest biodiversity: Ecology, values and outlook for white pines. Forest Pathology 40:186–225. doi:10.1111/j.1439-0329.2010.00655.x

Tomback, D. F., and K. A. Kramer. 1980. Limber pine seed harvest by Clark's nutcracker in the Sierra Nevada: Timing and foraging behavior. Condor 82:467–468.

Ullrich, P.A., Z. Xu, A. M. Rhoades, M. D. Dettinger, J. F. Mount, A. D. Jones, and P. Vahmani. 2018. California's drought of the future: A midcentury recreation of the exceptional conditions of 2012–2017. Earth's Future 6(11):1568-1587.

U.S. Fish and Wildlife Service. 2010. Endangered and Threatened Wildlife and Plants; 12-month Finding on a Petition to List the American Pikas as Threatened or Endangered. Federal Register 75 (26) 6438-6471. https://www.gpo.gov/fdsys/pkg/FR-2010-02-09/pdf/2010-2405.pdf#page=2

U.S. Fish and Wildlife Service. 2011. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition To List *Pinus albicaulis* as Endangered or Threatened With Critical Habitat. Federal Register 76 (138) 42631-42654. https://www.gpo.gov/fdsys/pkg/FR-2011-07-19/pdf/2011-17943.pdf

U.S. Fish and Wildlife Service. 2015. Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Notice of review, Federal Register 80 (247). https://www.gpo.gov/fdsys/pkg/FR-2015-12-24/pdf/2015-32284.pdf

U.S. Fish and Wildlife Service. 2016. Endangered and Threatened Wildlife and Plants; 90-Day Findings on 10 Petitions. Federal Register 81 (178). https://www.gpo.gov/fdsys/pkg/FR-2016-09-14/pdf/2016-22071.pdf

Vano, J. A., B. Udall, D. R. Cayan, J. T. Overpeck, L. D. Brekke, T. Das, H. C. Hartmann, H. G. Hidalgo, M. Hoerling, G. J. McCabe, K. Morino, R. S. Webb, K. Werner, and D. P. Lettenmaier. 2013. Understanding uncertainties in future Colorado River streamflow. Bulletin of the American Meteorological Society 95(1):59–78. doi:10.1175/BAMS-D-12-00228.1

Varner, J., M. S. Lambert, J. J. Horns, S. Laverty, L. Dizney, E. A. Beever, and M. D. Dearing. 2015. Too hot to trot? Evaluating the effects of wildfire on patterns of occupancy and abundance for a climate-sensitive habitat specialist. International Journal of Wildland Fire 24:921–932. https://doi.org/10.1071/WF15038

Vogan, P. J. and A. W. Schoettle. 2015. Selection for resistance to white pine blister rust affects the abiotic stress tolerances of limber pine. Forest Ecology and Management 344:110–119.

Warwell, M. V., G. E. Rehfeldt, and N. L. Crookston. 2006. Modeling contemporary climate profiles of whitebark pine (*Pinus albicaulis*) and predicting responses to global warming. Pages 139-142 *in* E. Goheen, editor. Proceedings of the Conference Whitebark Pine: A Pacific Coast Perspective. R6-NR-FHP-2007-01. Ashland, OR: USDA Forest Service.

Weeks, D., P. Malone, and L. Welling. 2011. Climate change scenario planning: A tool for managing parks into uncertain futures. Park Science 28:26–33.

Wilkening, J.L., and C. Ray. 2016. Characterizing predictors of survival in the American pika (*Ochotona princeps*). Journal of Mammalogy 97 1366–1375. https://doi.org/10.1093/jmammal/gyw097

Wilkening, J. L., C. Ray, E. A. Beever, and P. F. Brussard. 2011. Modeling contemporary range retraction in Great Basin pikas (*Ochotona princeps*) using data on microclimate and microhabitat. Quaternary International PACLIM: Proceedings of the 24th Pacific Climate Workshop, 2009 235:77–88. doi:10.1016/j.quaint.2010.05.004

Wilkening, J. L., C. Ray, and K. L. Sweazea. 2013. Stress hormone concentration in Rocky Mountain populations of the American pikas (*Ochotona princeps*). Conservation Physiology 1. doi:10.1093/conphys/cot027

Yandow, L. H., A. D. Chalfoun, and D. F. Doak. 2015. Climate tolerances and habitat requirements jointly shape the elevational distribution of the American pikas (*Ochotona princeps*), with implications for climate change effects. PLOS ONE 10:e0131082. doi:10.1371/journal.pone.0131082

Yu, N., C. Zheng, Y.-P. Zhang, and W. -H. Li. 2000. Molecular systematics of pikas (Genus *Ochotona*) inferred from mitochondrial DNA sequences. Molecular Phylogenetics and Evolution 16:85–95. doi:10.1006/mpev.2000.0776

Appendix 1. Team Assembled for the April 1, 2016, Climate Change Scenario Planning Workshop on American pikas at Oregon State University—Cascades, Bend, OR

Team Member	Agency
Holly Hartmann	Holly C. Hartmann Consulting
Jherime Kellermann	Crater Lake National Park Science & Learning Center and Oregon Institute of Technology
Connie Millar	US Forest Service Pacific Southwest Research Station
Tom Rodhouse	National Park Service Upper Columbia Basin Inventory & Monitoring Network
Doni Schwalm	Oregon State University
Matt Shinderman	Oregon State University - Cascades

Appendix 2. National Park Units in each of the partner Inventory and Monitoring Networks.

Partner Network	National Park Units
Klamath	Crater Lake National Park Lassen Volcanic National Park Lava Beds National Monument Oregon Caves National Monument Redwoods National & State Parks Whiskeytown National Recreation Area
Sierra Nevada	Yosemite National Park Sequoia National Park Kings Canyon National Park Devil's Postpile National Monument
Upper Columbia Basin	Big Hole National Battlefield City of Rocks National Reserve Craters of the Moon National Monument & Park Hagerman Fossil Beds National Monument Minidoka National Historic Site John Day Fossil Beds National Monument Lake Roosevelt National Recreation Area Nez Perce National Historic Park Whitman Mission National Historic Site

Appendix 3. Team assembled for the September 16, 2015, Climate Change Scenario Planning Workshop on whitebark pine at Southern Oregon University

Team Member	**Agency**
Alice Chung-MacCoubrey	National Park Service Klamath Inventory & Monitoring Network
Anna Iwaki-Mateljac	National Park Service, Washington Support Office (WASO)
Angelia Kegley	US Forest Service, Dorena Genetic Research Center
Bob Keane	US Forest Service Rocky Mountain Research Station
Devin Stucki	National Park Service Upper Columbia Basin Inventory & Monitoring Network
Diana Tomback	University of Colorado, Denver
Jen Beck	Crater Lake National Park
Jherime Kellermann	Crater Lake National Park Science & Learning Center and Oregon Institute of Technology
Jonathan Nesmith	National Park Service Sierra Nevada Inventory & Monitoring Network
Katie Johnson	Lassen Volcanic National Park
Mac Brock	Crater Lake National Park
Robyn Darbyshire	US Forest Service, Region 6, Pacific Northwest Research Station
Sean Smith	National Park Service Klamath Inventory & Monitoring Network

Appendix 4. Agenda and Reading List for the September 16, 2015, Climate Change Scenario Planning Workshop on Whitebark Pine at Southern Oregon University

Whitebark Pine Climate Change Scenario Planning Workshop

Agenda

- Introductions (9:00-9:15)
- Overview on the status of Whitebark pine – Bob Keane (9:20-9:45)
- Overview of scenario planning – Jherime Kellermann (9:45-10:15)

Break (10:15-10:30)

- Present and Discuss project purpose, Strategic challenge, Focal question(s), Desired outcomes (10:30-11 :00)
- Present logistics for afternoon (11:00-11:15)

Lunch (11:30-12:30)

- Breakout groups (12:30-14:00)
    - Identify critical environmental and climatic drivers of whitebark populations
        - Identify key uncertainties
        - Identify information needs/gaps generally or for particular areas or parks
        - Unique drivers for other western 5-needle pines?
        - Identify 1-3 questions for online survey of additional researchers & managers
- As a group, present and compile breakout group information (14:00-15:00)
    - Identify locations for future workshops and folks to invite to future scenario planning workshops – at least one per network

Continue the conversation @ Standing Stone Brewery (17:00)

Scenario Planning References

Fisichelli, N., C. Hawkins Hoffman, L. Welling, L. Briley, and R. Rood. 2013. Using climate change scenarios to explore management at Isle Royale National Park: January 2013 workshop report. Natural Resource Report NPS/NRSS/CCRP/NRR—2013/714. National Park Service, Fort Collins, Colorado. http://www.nps.gov/isro/learn/nature/upload/Using-Climate-Change-Scenarios-to-Explore-Management-at-lSRO.pdf

National Park Service, 2013. Using Scenarios to Explore Climate Change: A Handbook for Practitioners. National Park Service Climate Change Response Program. Fort Collins, Colorado. http://www.nps.gov/subjects/climatechange/upload/CCScenariosHandbookJuly2013.pdf

"Rehearsing the Future" – Scenario Planning in Alaska.
http://www.nps.gov/akso/nature/climate/scenario.cfm

Welling, L. et al. 2014. Climate Change Scenario Planning Summary. Crown Managers Partnership, 14th Annual Forum, Managing for Climate Change in the Crown of the Continent Ecosystem. March 17-19, 2014, Missoula, Montana.
http://static1.1.sqspcdn.com/static/f/808688/26133814/1428928480560/CMP-Forum-2014_Scenario-Planning-Report_FINAL201407171.pdf?token=bI5uksIbp3pF4eLtihTDIwxXPTw%3D

Winfree, R. et al. Climate Change Scenario Planning Lessons from Alaska. Alaska Park Science 12: 74-79. http://www.nps.gov/akso/nature/science/ak_park_science/PDF/Vol12-2/APS_Vol12-Issue2_74-79-Winfree.pdf

Other recommended readings

Monahan WB, Fisichelli NA (2014) Climate Exposure of US National Parks in a New Era of Change. PLoS ONE 9(7): e101302. doi:10.1371/journal.pone.0101302

Hansen, A. J., Piekielek, N., Davis, C., Haas, J., Theobald, D. M., Gross, J.E., Monahan, W.B., Oliff, T., & Running, S. W. (2014). Exposure of US National Parks to land use and climate change 1900-2100. Ecological Applications, 24, 484-502.

Appendix 5. Agenda for the April 1, 2016, Climate Change Scenario Planning Workshop on American pikas at Oregon State University—Cascades

2016 American Pikas Climate Change Scenario Planning workshop Agenda – "At a glance"

Friday, April 1

- 9:00 Convene at OSU Cascades
- 9:00-10:00 Introductions, overview, background, & status
- 10:00-11:00 Goals & Outcomes
- 11:00-12:00 Driver & Impact tables
- 12:00-1:00 Lunch (Catered)
- 1:00-2:00 D&I tables cont'd
- 2:00-5:00 Scoping and outline of manuscript

Saturday, April 2

- 9:00-1:00 Field trip to Newberry Crater National Monument – Meet at Hilton Garden Inn

Detailed Agenda

Friday, April 1

9:00 Quick introductions, backgrounds

9:15 Brief overview of project to date – Jherime

9:30 Brief overview of scenario planning – "A decision relevant science" – Holly

9:30-10:00 Brief review of regional "state of knowledge" of pikas in UCB, Klamath, Sierras – All

- A few quick slides or just a verbal summary of key advances, findings, problems, focal areas of research

10:00-11:00 Goals & Outcomes – The "Big Picture"

- What are the needs, goals, and potential for application of climate change scenario planning for pikas by management agencies?
    - How do we want to use the information/products we generate?
    - What are our expectations for future scenario planning actions?
- Develop foundations for informing scenario planning efforts

Lunch at 12:00

11:00-2:00 Driver and impact tables

1. Identify:
    a. Key drivers/triggers of change and
    b. Limitations to enacting/implementing management actions, and
2. Rank their uncertainty
3. Identify their potential impact on pikas (e.g. connectivity, food availability, physiological tolerance)
4. Identify key gaps in understanding

- Classify driver/triggers/limitations within the following areas (there will be overlap among these):
    - Climate
    - Biological/genetic
    - Ecological
    - Political/policy
    - Social
    - Economic/resources
    - Technological/feasibility
  - Consider:
    - Do these factors, uncertainties, or unknowns vary across spatial and temporal scales within and among regions?
    - Are there nested effects?

2:00-5:00 Scope and outline manuscript

- Target audience and goals?
- Sections and contributors?
- New modeling or analyses – consider implications of possible climate scenarios?
- Timeline

6:00 Happy hour and dinner at location TBD – Families welcome!

Saturday, April 2
9:00-1:00

- Meet at Hilton Garden Inn, carpool where possible to Newberry Crater
- Families welcome!
- Bring lunch

NPS 940/156549, August 2019

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

EXPERIENCE YOUR AMERICA TM