Protecting forest biodiversity:
Understanding climate change refugia for management

A George Melendez Wright National Park Service Climate Change Fellowship project

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CLIMATE CHANGE
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Contents

Abstract

A substantial portion of Yosemite, Sequoia, and Kings Canyon National Parks' floristic biodiversity occurs in refugia of various kinds. Cold refugia form at the intersection of cold-air drainages in basins and drainages from valleys up to mid-slope in relatively mesic areas and/or on north-facing slopes. In these sites, many species exist at the southern extent of their ranges and do not exist outside of refugia at this latitude. Climate change's predicted increased warmth and disturbances may cause local extirpation of some refugia species. Alternatively, these regions may become climatic refugia for other species which are currently common in the region, but could become rare as the climate changes and/or increasingly restricted to refugia. Cold refugia have distinct plant communities and may also have distinct ecological processes from surrounding areas, such as fire frequency or severity.

In the near future, Yosemite National Park plans to conduct prescribed burns to protect the residents adjacent to forests. These plans' ecological impacts on the cold-refugia plant communities found within this proposed burn sites are uncertain. Park managers need to know more about the fire ecology of cold refugia before they can take appropriate management action. Therefore, I review and synthesize geophysical and fire ecology research to enhance understanding of refugia in the Sierra Nevada mixed conifer forest.

As an NPS George Melendez Wright Climate Change Fellow, I will achieve these goals: (1) Identify potential refugia; (2) Examine published data for insights into the refugia fire ecology; and (3) Infer the vulnerability of refugia to fire, especially prescribed burns and/or high severity fire. Most importantly, this study will create a framework as regional land managers work to mitigate climate change's impacts on biodiversity by focusing on climate refugia and their distinct ecology. This information synthesis will enhance land managers' ability to protect refugia biodiversity.

Fellowship products

Current:

- Coordinated submission of Sierra Nevada fire history studies to the World Data Center for Paleoclimatology fire scar database (*1*)
- Created refugia focused EndNote library for Yosemite National Park
- Deployed climate sensor network in Yosemite National Park
- Attended Ecological Society of America's Climate Refugia Workshop in Eugene, OR 8/2013
- Presented project poster at CA-LCC's Southern Sierra Climate Change Workshop and Yosemite's Fire and Hydro-climate conference
- Wrote management report

Publications in preparation:

- Novel roles of refugia
- The fire ecology of Sierra Nevada cold-refugia

Special thanks

Many people including Arndt Hampe, Zack Holden, Alison Colwell, Martin Hutten, Brandon Collins, Gus Smith, and Eric Knapp gave their patient guidance to help me envision and realize this project.

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Special thanks to volunteers including Sponsored Project for Undergraduate participants Kate Clyatt, Madeline Green, and Jonathon Fluoroy for their help creating a cold refugia indicator plant guide; Sponsored Project for Undergraduate participants Shannon Fairchild, Kristine Grace, and Xuantong Wange for assistance with the climate sensor network collection and analysis; climate sensor solar shield construction team including Sasha Berleman, Stella Cousins, Chris Dow, Danny Fry, Anu Kramer, Katy Seto, and Eric Waller; climate sensor deployment volunteers participants Dave Campbell, Tom Reyes, Alison Colwell, and Janelle Cassiani.

Introduction

Why are refugia important?

Early climate change ideas predicted catastrophic species extinctions. As scientists investigated species response to climate change further, a more nuanced perspective emerged indicating that species may be able to persist in cold-refugia (*2*, *3*). These cold-refugia are believed to play an integral part in the rapid expansion of many species when the ice sheets retreated, provided a source propagules for rapid species migration (*4-10*). This phenomenon is especially apparent in complex terrain such as the mixed conifer zone of Yosemite National Park (Yosemite) which has cold-refugia. Here, Pacific Northwest species have disjunct populations in species such as *Taxus brevifolia* (Pacific yew), *Arbutus menziesii* (Pacific madrone), and *Lithocarpus densiflorus* (tanbark-oak) (Appendix A). While cold-refugia gained dramatic interest as important conservation areas (*2*), threats to their ecology and conservation have not been fully explored.

What are refugia?

Many people have tried to define cold-refugia based on biology (*11*) or climate (*3*). Keppel et al.'s (2011) biological definition of refugia is "habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions." Dobrowski et al. (2011) defines refugia to occur where extant climates (temperature and available water) are maintained during climate change. Together they form a holistic definition, a habitat which buffers climate and allows species to persist in and to potentially expand from under changing environmental conditions.

In the Sierra Nevada, cold-refugia (refugia) form at the intersection of relatively mesic areas with cold-air pools and/or north-facing slopes. Here, many species exist at their southern range extent and do not exist outside of refugia at this latitude. Climate change's predicted increased warmth and amplified disturbances cause local extirpation of some refugia species. Concomitantly, these regions become refugia for other species which are currently common in the region but may become rare and/or restricted to refugia with climate changes. Refugia not only have distinct communities, but they also exhibit distinct ecological processes from surrounding areas, such as fire frequency or severity.

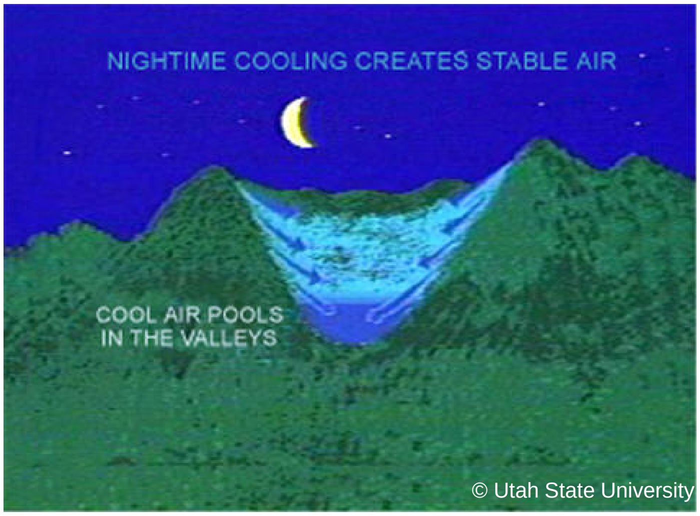


Figure 1 Cold-air pool landscape position and physics.

Project goals

Refugia are an important component of conservation management, but are poorly understood. Therefore, I review and synthesize geophysical and fire ecology research to enhance understanding of refugia in the Sierra Nevada mixed conifer forest in this management report. As an NPS George Melendez Wright Climate Change Fellow, I will achieve these additional goals: (1) Identify potential refugia; (2) Examine published data for insights into the refugia fire ecology; and (3) Infer the vulnerability of refugia to fire, especially prescribed burns and/or high severity fire. Most importantly, this study will create a framework as regional land managers work to mitigate climate change's impacts on biodiversity by focusing on climate refugia and their distinct ecology. This information synthesis will enhance land managers' ability to protect refugia biodiversity.

How will climate change alter cold-refugia?

Despite refugium's many conservation values, the conservation of an individual refugia or a network of refugium is not without reservation, especially due to limited conservation funding. Keppel and Wardell-Johnson (2012) highlight the importance of a refugia's climate buffering potential and projecting climate change and its biological effects (*2*). I expand 'climate change and its biological effects' to explicitly include species interactions (inter- and intra-specific) and ecological processes. In addition, land management needs to be addressed for refugia conservation (Figure 2).

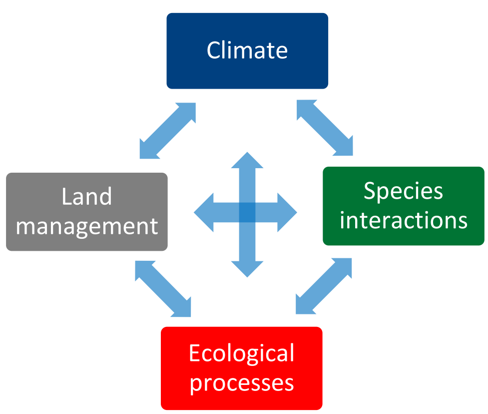


Figure 2. Cold-refugia ecology is complex and affected by climate, land management, species interactions, and ecological processes, and their interactions.

Changing climate

As Keppel and Wardell-Johnson (2012) discussed, refugium have distinct climates which change in synchrony or asynchrony with the regional climate (*2*). These climates either lag behind the surrounding climate or change at a slower rate i.e. buffer climate change (Figure 3); and these relationships are seasonally dependent (*12*). The buffered refugia are of greater conservation significance because they are more stable.

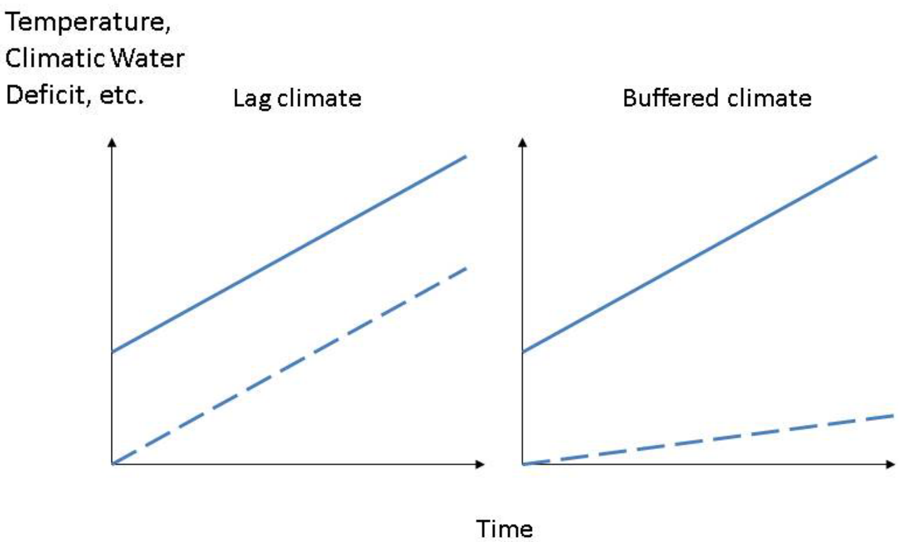


Figure 3. Refugia climates either lag behind the surrounding climate or change at a slower right i.e. buffer climate change.

Topographic drivers of climate in Yosemite, especially within cold-refugia are difficult to understand with limited published studies. Therefore, 90 LogTag temperature climate sensors were deployed in the Fall of 2012 to downscale climate and understand regional microclimate drivers. Because the majority of sensors were likely destroyed by the Rim Fire, I will retrieve and redeploy the sensors this Fall (2013) with assistance from the University of California at Berkeley's Sponsored Projects for Undergraduate students program.. The surviving sensor data will be reviewed for trends, but the small sample size will limit inference power. The unique climate and potential buffering capacity of Yosemite's cold-refugia will be evaluated by 2015 (*13-15*).

Changing fire regimes

Fire regimes, especially fire frequency and severity, are changing world wide due to land management and climate change. Refugia are at a greater risk from changing fire regimes (*16*) due to their predisposition to local extinction i.e. their small, isolated nature. Refugia also have unique fire ecology including fire frequency, fire severity, fire behavior, and fuels (*17*, *18*) (Figure 4).

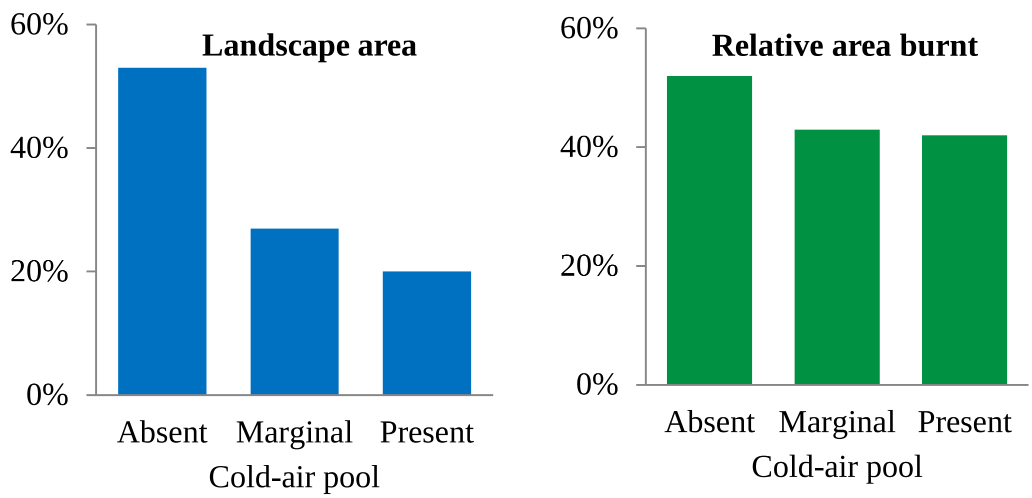
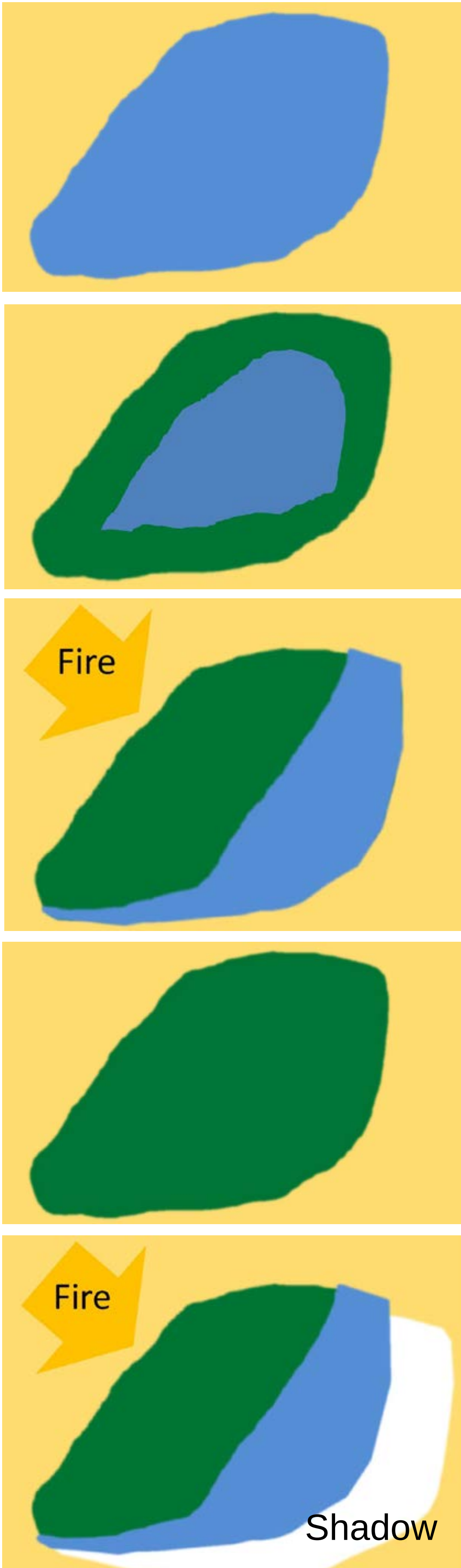


Figure 4. In Yosemite's mixed conifer zone, cold-air pools (CAPs) occupy about one-fifth of the total land area. Here, CAPs were less likely to burn than the surrounding area to burn from 1984 to 2010. Fires burned 20% less area when cold air pools were present, compared to the surrounding

Refugia in rugged terrain seperated by fire barriers such as rock or water are more likely to have decreased fire frequency than their surrounding terrain (*17*). However, these topographic controls diminish under climate change. If fire becomes driven by extreme events such as drought or wind storms, then refugium's historic fire barrier will no longer function (*18*). For example, the Rim Fire occurred during an extreme drought that dried fuel throughout diverse microclimates,making historically fire-resistant areas flammable. If historic fire barriers existed, they most likely did not function during this fire. Refugia with historic fire barriers are more susceptibale to high severity fire since fuel may have built up since they last burned.

'For example, the Rim Fire occurred during an extreme drought that dried fuel throughout diverse microclimates,making historically fire-resistant areas flammable. If historic fire barriers existed, they most likely did not function during this fire.'



Refugia are defined by their distinct climates which moderate fire behavior (Figure 5). Fire behavior is moderated by:

1. Temperature regime:

CAPs are cooler in the evening and morning but reach similar maximum daytime temperatures as surrounding areas.

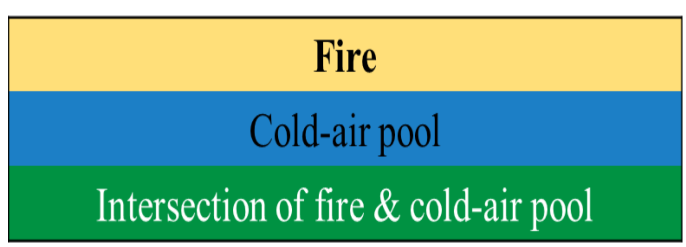
North-facing slopes are also cooler in the evening and morning but do not reach similar maximum daytime temperatures as surrounding areas.

2. Moisture regime:

CAPs have greater fuel moisture than the surrounding area because they occur in drainages and moisture loss is moderated by lower temperature.

North-facing slopes do not have additional moisture inputs, but nonetheless their moisture loss is moderated by lower temperatures. Fuel moisture differences have less fire behavior effects during late fall and/or droughts. (*19*)

Figure 5. The interaction of fire and CAP may be dependent upon fire behavior including the fire's direction, magnitude, and intensity. (A) Fires which move slowly (low magnitude) and release little energy (low intensity) may respond quickly to a refugium's microenvironment and not penetrate the CAP, whereas (B) fires with high magnitude and intensity may respond slowly to a CAP (burn a buffer around the perimeter), (C) and/or a larger region near the flame front, or (D) even burn the entire CAP. (E) There also may be a CAP fire shadow where a reduction in fire extent or severity may persist beyond the CAP boundary.



Refugia, especially in arid regions like Yosemite, have greater moisture, fuel production, and an unprecedented risk from fire (*3, 20, 21*). Refugia commonly occur in riparian areas which were heavily altered by fire suppression resulting in unprecedented amounts of fuel (more than five times greater than historic levels), leaving them susceptible to high severity fire that might be quite detrimental to biodiversity (*21*). If the climate becomes drier, these fuels have reduced moisture and availble to burn for a larger portion of the year. These additional fuels contribute to more frequent or severe fires. However, refugia may not be homologs to riparian areas. Fire is significantly less likely to occur in refugia than in other areas; refugia area burnt from 1984 to 2010 is only 80% of expected area in Yosemite National Park's mixed conifer zone (*22*) (Figure 4). Additionally, if fire occurs in refugia, then it is significantly less likely to be high severity fire. The combination of published and preliminary results gives rise to new questions for both refugia and riparian areas: *Are they influenced by alternative disturbance regime such fungal plant pathogens? Do they have similar fire regimes?*

Prescribed fires, especially in areas with heavy fuel loads that cause higher severity fires, threaten to extirpate rare plants occurring at their southern range extent because small populations are highly susceptible to extirpation from localized events. While prescribed fire and mechanical treatments in the short-term are an immediate threat to inhabitants of refugia, the long-term lack of fire exacerbate climate change's increasing disturbance threats to biodiversity, including increased fire frequency and severity (*23*, *24*). Increased fire frequency and severity can be moderated during some fire events, but cannot be mitigated during extreme fire events (*25, 26*). Active suppression tactics will only reduce risk in the short-term and are not likely to be deployed to protect refugia during extreme fires. (*27*)

Fire changing climate

Many studies have demonstrated that fine scale variation (vegetation, slope, aspect, soil moisture) in climate can have more variation than coarse scale variation (elevation, latitude) (*12, 13, 28, 29*) . Vegetation, slope, and aspect affect the duration and intensity of solar radiation, and heat loss. Moisture mediates the solar radiation absorption and loss.(*12*)

Some of these variables, both canopy and understory cover, are directly altered by fire (*12*). Ford et al. (2013) demonstrated that fine-scale biological drivers, such as canopy and understory cover, can significantly affect soil surface temperatures at a greater magnitude than elevation (Table 1). While these results cannot strictly be transferred to Yosemite National Park, they offer insight into the magnitude at which fire alters the vegetation and thus the local climate.

Table 1. Results from Ford et al. (2013) demonstrate that experimentally removing vegetation, much like a high severity fire, significantly alters local climates at Mt. Rainer National Park. Results include the mean and standard error.

Removing canopy cover:	Removing understory cover:
• Snow disappears 19 +/-7 days earlier	• Snow disappears 0.6 +/-7 days earlier
• Maximum temperature increase 1.9 +/- 0.2 °C	• Maximum temperature increase 1.5 +/- 0.1 °C
• Minimum temperature decrease 0.4 +/- .03 °C	• Minimum temperature decrease 0.1 +/- .1 °C

Soil moisture is also indirectly altered by fire (*30*); Fire alters vegetation and thus alters soil moisture. Specifically, vegetation has the potential to intercept precipitation with foliage, mediate soil moisture with foliage, reduce soil erosion with their fine roots, convert surface water to ground water by slowing the water's velocity, and contribute to evapotranspiration (*30*-*33*). No publications were located which focused on experimentally altering hydrology to change microclimate.

Changing species interactions

Species interactions will change potentially dramatically. Changes may include phenology, behavior, population age distribution, size and structure of individuals, pulse recruitment, population size, and meta-population dynamics (*34, 35*). In fact, Cahill et al. (2013) suggest changes in species interactions are the driving cause of species extinctions rather than available climate space (*36*). Species persistence in cold-refugia may occur naturally or require significant management to overcome species interactions.

The ability of refugia to persist is dependent upon maintaining environmental, fundamental, and realized niches[1] (*34, 35*) (Figure 6). The realized niche changes due to changes in intra and

[1]Environmental niche is the climate where the species can persist.
Fundamental niche is the area where species can persist given interactions with other species.
Realized niche is where species are present i.e. where the environmental and fundamental niche overlap.

interspecific species interactions (*34*, *36*). Refugia would not be able to maintain current species due to these changes. The pre-climate change refugia state and changes to both the environment and species interactions will uniquely affect the outcome of each refugium.

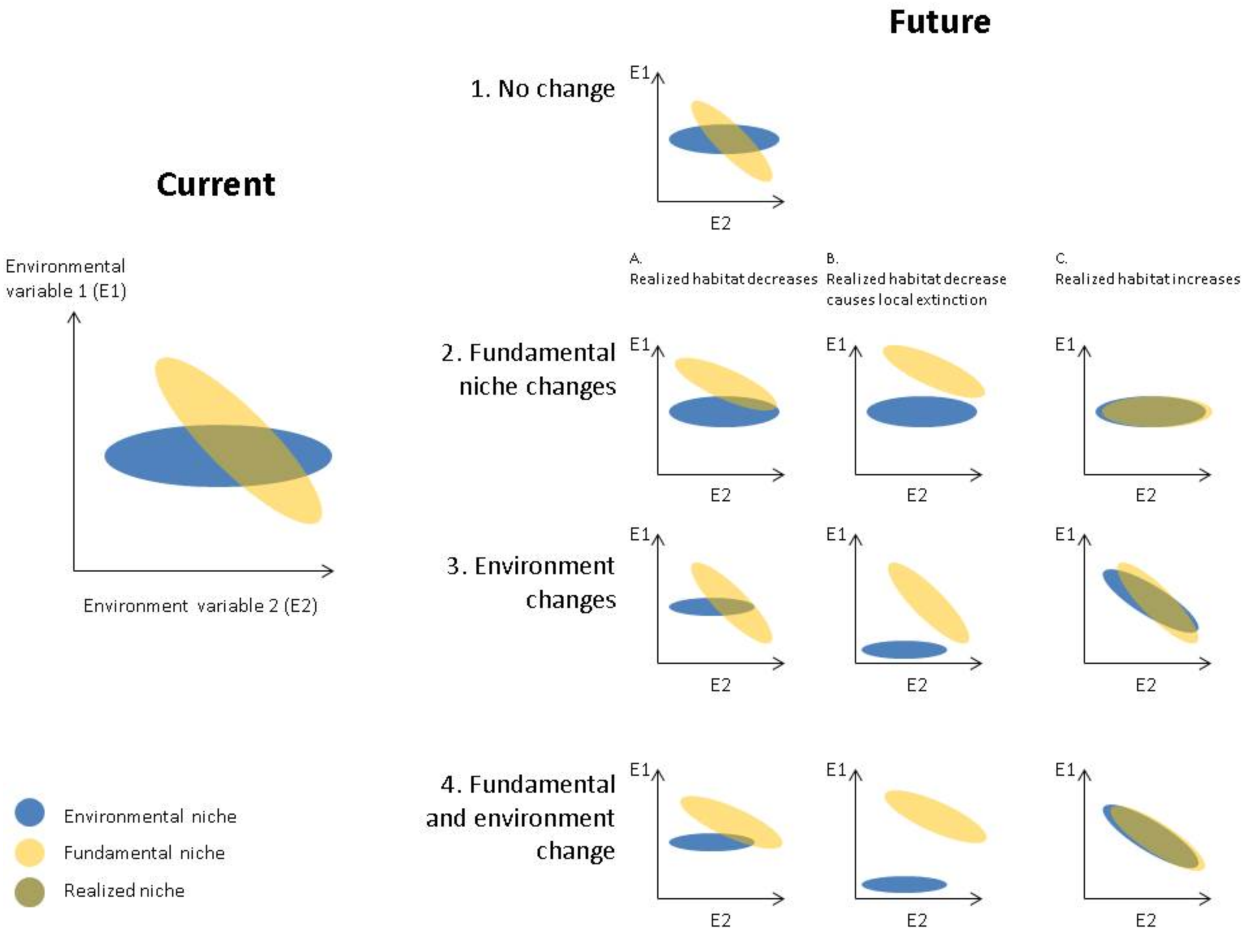


Figure 6. Adapted from Jackson and Overpeck (2000):

1. Best case scenario: Both climate and fundamental niche are maintained. The refugia will persist.
2. Climate is maintained, but the fundamental niche shifts due to changing species interactions. This will cause the realized niche to shift and either: decrease in size (A), decrease in size until the population is locally extinct (B), or increase in size (C).
3. Climate is not maintained, but the fundamental niche is maintained. This will cause the realized niche to shift: This will cause the realized niche to shift and either: decrease in size (A), decrease in size until the population is locally extinct (B), or increase in size (C).
4. Neither Climate nor fundamental niches are maintained. This will cause the realized niche to shift: This will cause the realized niche to shift and either: decrease in size (A), decrease in size until the population is locally extinct (B), or increase in size (C).

What are novel roles for cold-refugia under climate change?

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Despite widespread interest, refugia may be overlooked by others as a climate change mitigation strategy given their common designation as a short-term resistance strategy (*27, 37, 38*). Refugia's role in ecology may also change (*11*). Historically refugia shrunk and expanded as they did during glacial and interglacial periods. In contrast, species which currently persist in refugia may not be able to expand due to the projected magnitude and unidirectional nature of climate change (*39*). *If refugia may be the last place species exist before extinction, then can we call these areas refugia as per Keppel et al.'s (2011) definition (11)?* Nonetheless, refugia have garnered much attention and have an important role in the conservation toolbox which we describe (*2*).

Refugia may function as part of resistance, resilience, and/or response strategies (Table 2). Protecting refugia is commonly identified as a climate change resistance strategy, but their protection also functions in the resilience and response frameworks. Resistant strategies include fortifying areas from climate change and disturbances. Resilient strategies include managing areas to withstand climate change and disturbances. Response strategies include facilitating changes to climate change adapted species, communities, and structures. Most actions are not exclusively in one framework. A combination of these strategies is thought to best aid conservation. Resistance and resilience strategies may only delay the inevitable repercussions of climate change. (*27, 37, 38*)

Table 2. Refugia play an important and evolving role in conservation.

	Resistance	Resilience	Response
Historical role of refugia			
Place for species to exist in, retreat to, and expand from (*11*)	X	X	X
Additional strategies			
Short-term refuge during disturbances (*2*)		X	X
Gardens and source propagules for assisted migration (*37*)			X
Important role in landscape heterogeneity	X	X	X
Natural history museum	X		
Create and maintain refugia for any of the described roles			X

Refuge

Refugia have been defined by some as a place where species may persist on an evolutionary time scale (*11*), but species may be able to take short-term refuge in refugia as well (*40*). During extreme, but short-term disturbances species may be able to exist in, retreat to, and expand from refugia. Refuge will be increasingly important as disturbance events become more frequent and/or sever as predicted with climate change.

Assisted migration

Refugia may be an asset for planned or impromptu assisted migration projects (*37*). Refugia may function as gardens where propagules can be cared for before or during transplanting. They may have source propagules for impromptu assisted migration project which occur after major environmental changes. The small carrying capacity of many climate refugia imposes strict limits on population size while their geographical isolation restricts opportunities for meta-population dynamics. Survival under such conditions renders relict populations prone to evolutionary processes such as genetic drift and local adaptation (*41*). It has consequently been argued that they could harbor genotypes with greater tolerance to climatic stress (*42, 43*). Yet empirical evidence remains scant and such expectations might be overly optimistic.

Landscape heterogeneity

Diverse environmental and species niches which occur near one another may reduce the effects of climate change. Refugia may resist climate change effects by buffering climate. The nearby placement of the refugia to other areas reduces the distance a species needs to travel to maintain its climate, i.e. the velocity of climate change, which enhances refugia's role as both a refuge and refugia (*44*). For example, California's high biodiversity has been attributed to topographic buffering. This topographic buffering is believed to allow floral species to persist longer than areas without buffering. While new species arise at the same rate, species extinction rates are slowed, and greater biodiversity accumulates (*45*).

Natural history museum

Refugia may be natural history museums. As climate shifts, common species may become restricted to areas which maintain historic climate. People will be able to visit these sites, see plants they remember from their youth, and learn about how climate change has dramatically altered natural systems.

Create and maintain refugia

Refugia could be created by planting desired species in areas which buffer climate for in-situ conservation (*46*). Refugia may also need to be maintained with desired species assemblages due to the effect of climate change on species interactions and ecological processes. Possible response actions include seed bank supplements; transplantation; watering; thinning or removing undesirable species, phenotypes, or genotypes. We may be able to utilize naturally cool places, such as cold-air pools, by protecting or enhancing tree cover that protects cold-air pools from mixing into the surrounding atmosphere or by enhancing dams to allow cold air to be stored in pools desired locations.

Conclusion

Oliver et al. (2012) advise conservation planners that their "highest priority (is) to reduce negative edge effects and improve in-situ management of existing habitat patches ". Refugia do exactly this, allowing in-situ management of habitat patches (*46*). Refugia are complex habitats guided by species interactions, climate, and ecological processes that may interact with one another and change with climate. Therefore, protecting the land associated with refugia is not sufficient to protect the biological and physical properties of refugia. While managers will be asked to make decisions about refugia without understanding their full ecological complexity, they must understand that refugia are not static and are likely to have novel roles and ecology.

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Appendix A. Species at their southern range in the central Sierra Nevada

Alison Colwell and Martin Hutten compiled potential refugia indicators, vascular and non-vascular species at their southern range extent in the central Sierra Nevada.

Ahtiana pallidula

Acer glabrum

Adenocaulon bicolor

Alectoria sarmentosa

Allotrpa virgata

Arbutus menziesii

Arctostaphylos manzanita ssp. *manzanita*

Arctostaphylos mewukka ssp. *mewukka*

Arnica latifolia

Asarum lemmonii

Botrychium tunux

Carex diandra

Carex pachystachya

Carex viridula

Cephalozia lunulifera

Cerastium beeringianum (var. capillare)

Cladonia umbricola

Claopodium bolanderi

Conostomum tetragonium

Cyphelium karelicum

Cypripedium montanum

Galium mexicanum var. *asperulum*

Githopsis diffusa ssp. *robusta*

Githopsis pulchella ssp. *campestris*

Githopsis pulchella ssp. *pulchella*

Githopsis pulchella ssp. *serpenticola*

Gratiola neglecta

Helodium blandowii

Hypogymnia tubulosa

Japewia subaurifira

Japewia tornoense

Leptosiphon bolanderi

Leucolepis acantheneuron

Limnanthes alba ssp. *versicolor*

Limnanthes striata

Lithocarpus densiflorus

Marsupella sparsifolia

Mimulus inconspicuus

Mimulus kelloggii

Minuartia pusilla

Minuartia rubella

Minuartia stricta

Moerckia blyttii

Myrica hartwegii

Myurella julacea

Narthecium californicum

Nephroma helveticum

Nephroma resupinatum

Pachistima myrsinites

Parmeliella parvula

Parmeliopsis hyperopta

Perideridia howellii

Perideridia kelloggii

Phoenocaulis cheiranthoides

Placopsis lambii

Pleuricospora fimbriolata

Polytrichum sexangulare

Pseudotsuga menziesii

Riccardia latifrons

Rinodina disjuncta

Scapania gymnostomophila

Sidalcea diploscypha

Sidalcea glaucescens

Silene invisa

Stereocaulon glareosum

Stereocaulon rivulorum

Taxus brevifolia

Trientalis latifolia

Tritomaria exsectiformis

Vaccinium sp.

Veronica cusickii