Seeps and Springs

Northern California Climate Change Vulnerability Assessment Synthesis

***An Important Note About this Document:** This document represents an initial evaluation of vulnerability for seeps and springs in northern California based on expert input and existing information. Specifically, the information presented below comprises vulnerability factors selected and scored by regional experts, relevant references from the scientific literature, and peer-review comments and revisions (see end of document for a glossary of terms and brief overview of study methods). The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

Peer reviewers for this document included Kurt Fesenmyer (Trout Unlimited), Nina Hemphill (U.S. Forest Service), and Rene Henery (Trout Unlimited and University of Nevada, Reno). Vulnerability scores were provided by Nathaniel Seavy (Point Blue Conservation Science). Upper Lake workshop participants provided additional comments on the climate change vulnerability of this habitat.

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Habitat Description

Springs and seeps (i.e., low-discharge springs) are the physical locations where groundwater is discharged from aquifers to the Earth's surface (Springer & Stevens 2009), with discharge rates varying seasonally depending on the depth and size of the supporting aquifers (Howard & Merrifield 2010). Deep aquifers are often confined or semi-confined, meaning that an impermeable layer of dirt, clay, and/or rock prevents water from seeping directly from the ground surface down into the aquifer below (Winter et al. 1998). This results in longer delays in recharge and longer water residence time (Healy & Cook 2002). Shallow, unconfined aquifers experience more rapid recharge as water percolates from the surface directly into the aquifer (Healy & Cook 2002). Seeps and springs support unique, biologically rich ecosystems that can include aquatic, wetland, and terrestrial species that are dependent on or benefit from groundwater for persistence (Howard & Merrifield 2010).[1]

Springs are critical resources for human communities across the region (Howard & Merrifield 2010; Cook et al. 2014; Grantham 2018), including northern California tribes (HVTEPA 2008; Karuk DNR 2009; Cozzetto et al. 2018). Seeps and springs support the ecological, spiritual, and material culture of the tribes, and supply tribes with drinking and irrigation water, cold-water food storage, and dilution of low-quality water (HVTEPA 2008; Karuk DNR 2009; Cozzetto et al. 2018). Seeps and springs also support plant species that provide medicinal benefits and other culturally-valued flora and fauna (Karuk DNR 2009; Norgaard et al. 2016).

Executive Summary

The relative vulnerability of seeps and springs in northern California was evaluated as moderate by regional experts due to moderate sensitivity to climate and non-climate stressors, moderate-high exposure to projected future climate changes, and moderate adaptive capacity.

Seeps and Springs	**Rank**	**Confidence**
Sensitivity	Moderate	Moderate
Future Exposure	Moderate-High	Moderate
Adaptive Capacity	Moderate	Moderate
Vulnerability	**Moderate**	**Moderate**

Sensitivity & Exposure Summary	
	Climate and climate-driven factors: • Precipitation amount, snowpack, soil moisture, and drought *Disturbance regimes*: • Wildfire *Non-climate stressors*: • Water withdrawal/extraction, agriculture, development, pollution, livestock grazing, fire suppression

Seep and spring ecosystems are sensitive to climate stressors that alter groundwater recharge and discharge, including changes in snowpack and precipitation amount, drought severity and frequency, and soil moisture. Drier future conditions will likely reduce the rate and magnitude of groundwater discharge, impacting plants and animals associated with seep and spring ecosystems and potentially leading to shifts in community composition or type. Periodic wildfire can be beneficial to groundwater-dependent ecosystems, but altered fire regimes as a result of climate change may alter patterns of runoff and recharge, in addition to possible direct

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[1] Many rivers, lakes, freshwater wetlands, and underground cave/karst systems are dependent on groundwater influences. However, this assessment will focus primarily on seeps and springs that are not closely associated with these systems, in part because the others are considered more broadly in other assessments.

impacts (i.e., injury or mortality) on species associated with these ecosystems. Non-climate stressors such as water withdrawal/extraction, development, and pollution have also altered groundwater dynamics, degraded water quality, and increased stress on groundwater-dependent plant communities. Groundwater pumping, in particular, has led to the loss of stored groundwater and reduced spring discharge in many areas.

Adaptive Capacity Summary	*Factors that enhance adaptive capacity*: + Deep aquifers less affected by short-term climate variability + Ability to provide thermal and hydrologic refugia for a variety of plants and animals + Growing public interest in managing lands for water source protection *Factors that undermine adaptive capacity*: – Shallow systems less able to resist fluctuations in temperature and precipitation – Threatened by groundwater withdrawals for municipal and agricultural purposes – Lack of research on groundwater dynamics in a changing climate and little data available on seep/spring locations

Seep and spring ecosystems are distributed widely but unevenly throughout northern California. Although they support high levels of biodiversity and ecosystems often include many rare/endemic species and unique species assemblages, the isolation of these systems reduces the potential for associated flora and fauna to shift their range in response to climate changes and disturbances. Additionally, land use and management activities (e.g., groundwater depletion, pollution) have significantly impacted ecosystem integrity in many areas. Management options that may increase resilience to climate impacts include reducing anthropogenic water withdrawals, reintroducing beavers to enhance landscape water storage and groundwater recharge, managing grazing intensity, and providing guidance for timber harvest and forest management to lessen their impacts on seep and spring ecosystems.

Sensitivity and Exposure

Seeps and springs were evaluated by regional experts as having moderate overall sensitivity (moderate confidence in evaluation) and moderate-high overall future exposure (moderate confidence) to climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors.

In general, warmer, drier conditions as a result of climate change are likely to increase the dependence of seep and spring ecosystems on groundwater discharge (Vuln. Assessment Reviewer, pers. comm., 2019) while simultaneously affecting the quality and quantity of available groundwater (Earman & Dettinger 2011; Kløve et al. 2014; Meixner et al. 2016). However, projecting future conditions for seeps and springs is difficult due to the complex mechanisms that affect groundwater recharge, discharge, and quality (Earman & Dettinger 2011; Kløve et al. 2014). The response of groundwater to climate is highly varied depending on local geology (e.g., bedrock permeability and porosity), aquifer characteristics (e.g., size, depth, confined vs. unconfined), hydrologic regime (i.e., snow-dominated vs. rain-dominated), land use/cover, and anthropogenic water withdrawals (Winter et al. 1998; Healy & Cook 2002;

Scanlon et al. 2005; Earman & Dettinger 2011; Flint et al. 2013). For instance, shallow, unconfined aquifers generally respond to changes in climate conditions at sub-annual to annual time scales, while impacts may be delayed by up to several decades in deeper, confined aquifers (Healy & Cook 2002; Kløve et al. 2014).

Sensitivity and future exposure to climate and climate-driven factors

Regional experts evaluated seeps and springs as having moderate-high sensitivity to climate and climate-driven factors (moderate confidence in evaluation), with an overall high future exposure to these factors within the study region (moderate confidence). Key climatic factors that affect seeps and springs include precipitation (rain and snow) amount, snowpack, soil moisture, and drought.[2]

Precipitation amount, snowpack, soil moisture, and drought

The greatest impacts on seeps and springs are likely to be those factors that affect the magnitude and timing of groundwater recharge, including changes in precipitation amount and intensity, snowpack depth, timing of snowmelt/runoff, and drought (Hiscock et al. 2012; Grantham 2018). The mechanism of aquifer recharge (i.e., rain vs. snow) and elevation play a critical role in vulnerability for groundwater-dependent ecosystems (Vuln. Assessment Reviewer, pers. comm., 2019). In snowpack-dominated recharge areas at higher elevations, a greater proportion of precipitation occurring as snow and earlier timing of snowmelt is associated with increased early-season groundwater recharge (Sutinen et al. 2008; Okkonen & Kløve 2010; Veijalainen et al. 2010). However, models suggest that earlier snowmelt recession is also associated with reduced summer groundwater discharge from shallow aquifers due to earlier depletion of stored water (Huntington & Niswonger 2012). In precipitation-dominated groundwater recharge areas, which usually include lower elevations and coastal regions, shifts in precipitation regimes toward shorter winters and prolonged dry seasons, coupled with increased frequency of drought, may limit recharge to local groundwater systems (Grantham 2018). If a greater proportion of annual precipitation falls during heavy precipitation events, increased surface water runoff is likely to decrease groundwater recharge and increase flooding in low-lying areas (Bates et al. 2008; Grantham 2018).

In some parts of California, springs associated with shallow aquifers have already gone dry during periods of drought (Vuln. Assessment Reviewer, pers. comm., 2019). For instance, Yurok tribal members and resource managers noted that many springs went dry during the recent severe multi-year drought (~2013–2016), reducing surface water flows and drinking water supplies (Cozzetto et al. 2018). In other parts of the state, large springs associated with volcanic aquifers that are principally fed by snowmelt are yielding water that has a residence time of over 60 years (Vuln. Assessment Reviewer, pers. comm., 2019). While these long hydraulic residence times suggest delayed response to climate changes, it is unknown whether the aquifers have lower vulnerability to climate change when longer time scales are considered (Vuln. Assessment Reviewer, pers. comm., 2019).

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[2] All climate and climate-driven factors presented were ranked as having a moderate or higher impact on this habitat type.

Most plant species associated with seep and spring ecosystems are facultative or obligate phreatophytes (i.e., species that access groundwater directly through their root systems; Huntington et al. 2016). While these species are somewhat buffered during periods of low precipitation, extended drought and/or longer-term shifts in ecosystem water dynamics that result in lowered groundwater levels can decrease plant productivity, increase mortality, and ultimately lead to shifts in habitat structure and composition (Naumburg et al. 2005; Kløve et al. 2014; Huntington et al. 2016; Dwire et al. 2018). Plant communities adjacent to small springs and/or shallow aquifers are likely more vulnerable to altered hydrology compared to those associated with large springs (Dwire et al. 2018).

Regional Precipitation, Snowpack, Soil Moisture, & Drought Trends[3]	
Historical & current trends: • 2.6–9.4 cm (1.0–3.7 in) increase in mean annual precipitation between 1900 and 2009 for the Northwestern California, Southern Cascade, and Great Valley ecoregions (Rapacciuolo et al. 2014) • 15–39% decrease in April 1 snow water equivalent (SWE) between 1951 and 2010 for the Northwestern California and Southern Cascade ecoregions (Flint et al. 2013) • No trends available for soil moisture • Drought years have occurred twice as often over the last two decades compared to the previous century (Diffenbaugh et al. 2015) • 2012–2014 drought set records for lowest precipitation, highest temperatures, and most extreme drought indicators on record (Griffin & Anchukaitis 2014; Diffenbaugh et al. 2015)	*Projected future trends:* • 23% decrease to 38% increase in mean annual precipitation by 2100 (compared to 1951–1980) for the North Coast, Northern Coast Range, Northern Interior Coast Range, Klamath Mountain, Southern Cascade, and Great Valley ecoregions (Flint et al. 2013; Flint & Flint 2014)[4] • Decreases in April 1 SWE by 2100 (compared to 1951–1980; Flint et al. 2013; Flint & Flint 2014): ○ 86–99% decrease on the North Coast ○ 82–99% decrease in the Northern Coast Range ○ 99–100% decrease in the Northern Interior Coast Range ○ 72–94% decrease in the Klamath Mountains ○ 61–89% decrease in the Southern Cascades • Seasonal changes are projected to be more significant as the wet season becomes wetter and shorter (i.e., later onset of fall rains and earlier onset of summer drought) and the dry season becomes drier and longer (Pierce et al. 2018; Swain et al. 2018)

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[3] Trends in climate factors and natural disturbance regimes presented in this and subsequent summary tables are not habitat-specific; rather, they represent broad trends and future projections for the study region. The precipitation, temperature, climatic water deficit, and snowpack projections for this project are derived from the Basin Characterization Model, which uses modified Jepson ecoregions (Flint et al. 2013; Flint & Flint 2014). Projections for all other factors are based on a review of relevant studies in the scientific literature. For this project, exposure was evaluated by calculating the magnitude and direction of projected change within the modified Jepson ecoregions that include habitat distribution within the study geography.

[4] Projections for changes in annual and seasonal precipitation by ecoregion can be found in the full climate impacts table (https://bit.ly/2LHgZaG).

Regional Precipitation, Snowpack, Soil Moisture, & Drought Trends[3]	
	• Overall, interannual variability is expected to increase (Pierce et al. 2018; Swain et al. 2018) • Decreased top-level soil moisture is likely even if precipitation increases due to temperature-related changes in evaporative demand (Pierce et al. 2018) • Drought years are twice as likely to occur over the next several decades due to increased co-occurrence of dry years with very warm years (Cook et al. 2015) • 80% chance of multi-decadal drought by 2100 under a high-emissions scenario (Cook et al. 2015) • Severe droughts that now occur once every 20 years will occur once every 10 years by 2100 and once-in-a-century drought will occur once every 20 years (Pierce et al. 2018)
Summary of Potential Impacts on Habitat *(see text for citations)*	
• Changes in the timing and magnitude of groundwater recharge • Increased water stress for associated vegetation, resulting in growth reductions, shifts in species composition, and injury or mortality	

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated seeps and springs as having low-moderate sensitivity to changes in natural disturbance regimes (moderate confidence in evaluation), with an overall moderate-high future exposure to these stressors within the study region (moderate confidence). The key natural disturbance regime that affects seeps and springs is wildfire.[5]

Wildfire

Wildfire influences groundwater recharge rate by altering vegetation distribution, which in turn affects infiltration from precipitation, how plants use water, and the resulting groundwater levels (DeBano et al. 1998; Biswell 1999). Vegetation loss in burned areas exacerbates erosion and mass wasting and high-intensity fires can also make soil hydrophobic for a period of time, increasing runoff and reducing percolation and landscape water retention on the landscape (Doerr et al. 2000; Mao et al. 2019; Vuln. Assessment Reviewer, pers. comm., 2019).

Fire return intervals in ecosystems associated with seeps and springs likely vary according to the composition and structure of surrounding upland vegetation, as well as topographic (e.g., slope, aspect) and environmental conditions (Skinner 2003; Skinner et al. 2018). However, vegetation alliances typically associated with seeps and springs may be less vulnerable to

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[5] This disturbance was ranked as having a low or low-moderate impact on this habitat type.

wildfire than the surrounding areas due to higher moisture levels. For instance, California pitcher plants (*Darlingtonia californica*) are often associated with seeps on ultramafic substrates (CNPS 2019), and the presence of water likely limits fire risk (Crane 1990). Fire can spread more readily in the late summer when discharge rates are at their lowest, as well as in very dry years (Skinner et al. 2018). Fire may also be more likely to occur after an early frost or other disturbance has killed a high proportion of the aboveground herbaceous material, which later dries out and acts as fuel (Skinner et al. 2018).

Regional Wildfire Trends

Historical & current trends:

- 85% of U.S. Forest Service lands in northern California are burning less frequently compared to pre-1850 fire return intervals, largely due to fire suppression (Safford & Van de Water 2014)
- Fire size and total area burned increased on U.S. Forest Service lands in northwestern California between 1910-2008, with the highest values occurring after 2000 (Miller et al. 2012)
- Changes in large fires (over 400 ha) in the inland northern California/Sierra Nevada region since the 1970s (Westerling 2016):
    - 184–274% increase in frequency
    - 270–492% increase in total area burned
    - 215% increase in length of the fire season
- Changes in fire size, area burned, and fire frequency over the past several decades remain well below historical tribally-influenced frequency and extent of burning in California (Stephens et al. 2007)
- No significant trends in the average areal proportion of high-severity fire were documented in northwestern CA from 1984–2008 (Miller et al. 2012; Parks et al. 2015; Law & Waring 2015; Keyser & Westerling 2017)
    - The relatively short period of record for fire severity data may obscure long-term trends
    - To date, there are no peer-reviewed studies on trends in northern California fire severity that include data from the last ten years

Projected future trends:

- State-wide, up to 77% increase in mean annual area burned and 50% increase in the frequency of extremely large fires (>10,000 ha) by 2100 (Westerling 2018)
    - Greatest increases in burned area (up to 400%) occur in montane forested areas in northern California (Westerling et al. 2011; Westerling 2018)
    - Less significant increases or possible decrease along the North Coast (Westerling et al. 2011)
- Little projected change in fire severity in northwestern California by 2050 in models based solely on historical fire-climate relationships (Parks et al. 2016)
    - However, human activity and fuel buildup from decades of fire suppression have altered historical fire-climate relationships (Taylor et al. 2016; Syphard et al. 2017; Wahl et al. 2019), and projections that incorporate these factors suggest that more significant increases in fire severity and size may occur (Mann et al. 2016; Wahl et al. 2019)
- The majority of impacts to natural and human ecosystems come from extreme fire events (i.e., fires that have a low probability of occurring in any given place and time), which are likely to increase over the coming century (Westerling 2018)
    - Generally, these patterns are not well-represented in studies that evaluate indices of mean fire size, intensity/severity, etc.

Regional Wildfire Trends
Summary of Potential Impacts on Habitat *(see text for citations)*
- Changes in groundwater recharge rate due to altered vegetation cover and composition, as well as changes in soil properties (e.g., increased water repellency)

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated seeps and springs as having moderate-high sensitivity to non-climate stressors (moderate confidence in evaluation), with an overall moderate current exposure to these stressors within the study region (moderate confidence). Key non-climate stressors that affect seeps and springs include water withdrawal/extraction, agriculture, development, pollution, livestock grazing, and fire suppression.[6]

Water withdrawal/extraction, development, and pollution

Groundwater pumping for agricultural, municipal, or industrial uses is associated with declines in aquifer water storage (Famiglietti et al. 2011; Scanlon et al. 2012; Russo & Lall 2017; Thomas & Famiglietti 2019) and spring discharge (Vuln. Assessment Reviewer, pers. comm., 2019), as well as decreased vigor in vegetation associated with spring ecosystems (Huntington et al. 2016). Groundwater pumping can impact groundwater supplies on an immediate basis, even in deep aquifers that normally experience delayed response to changing environmental conditions (Russo & Lall 2017). Water withdrawals may occur from larger springs on private lands by water bottling companies and other users (Vuln. Assessment Reviewer, pers. comm., 2019). Climate-mediated increases in groundwater extraction and surface water withdrawals are likely to occur during periods of low precipitation and drought (Russo & Lall 2017; Thomas & Famiglietti 2019). Increases in water demand driven by climate change will be further exacerbated by growing human populations in the region (Medellín-Azuara et al. 2007).

Expanding cannabis (*Cannabis sativa* or *C. indica*) production presents a current and increasing future threat to groundwater integrity in northern California (Vuln. Assessment Workshop, pers. comm., 2017; Butsic et al. 2018). Between 2012 and 2016, the number of cultivation sites (both legal and illegal) and total cultivated area almost doubled, while the number of plants cultivated quadrupled; the majority of the expansion occurred in environmentally sensitive areas including many remote areas (Butsic et al. 2018) where water sources are likely fed by springs (Vuln. Assessment Reviewer, pers. comm., 2019). Cannabis growers may extract groundwater from wells in times of low streamflow, trucking it to distant growing sites; however, the amount of groundwater withdrawal and its impact on associated ecosystems has not been well documented (Bauer et al. 2015). Herbicides and pesticides used for cannabis cultivation can also pollute nearby water sources (Bauer et al. 2015).

Land-use conversion to development and agriculture additionally impacts soil infiltration, runoff, and water quality (Winter et al. 1998; Scanlon et al. 2005). Runoff from impervious

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[6] Of these non-climate stressors, only water withdrawal/extraction, development, and pollution were ranked as having a moderate or higher impact on this habitat type.

surfaces and/or compacted soils in areas converted to agriculture or development can also introduce contaminants into shallow aquifers that are directly connected to surface water sources (Winter et al. 1998).

Livestock grazing

Livestock grazing can degrade groundwater-dependent systems by compacting soils, removing vegetation, and increasing nutrient inputs, with impacts depending on grazing intensity. Soil compaction decreases groundwater recharge and increases runoff, potentially impacting water supplies for seeps and springs (Belsky et al. 1999; Vuln. Assessment Reviewer, pers. comm., 2019). Grazing can reduce vegetation height and cover (Jackson & Allen-Diaz 2006; Nusslé et al. 2017), and is associated with changes in herbaceous species composition and diversity (Jackson & Allen-Diaz 2006). The abundance of aquatic fauna, such as springsnails (*Pyrgulopsis* spp.), can also be reduced by livestock grazing around springs (Hershler et al. 2014). In addition, concentrated livestock feeding operations increase nutrient pollution that affects water quality in groundwater-dependent systems (Brown et al. 2011). Indirectly, seep and spring ecosystems can also be impacted by human alterations intended to increase grazing suitability for livestock (Vuln. Assessment Reviewer, pers. comm., 2019).

Fire suppression

The legacy of fire suppression in northern California has led to widespread shifts in vegetation structure and composition, which, in turn, alters the water balance across the landscape (Biswell 1999; Skinner et al. 2018). For instance, the encroachment of deep-rooted trees and shrubs into areas formerly dominated by grasses increase evapotranspiration rates in summer and fall, reducing water availability for groundwater recharge (Biswell 1999). Conifer encroachment into open areas can also reduce surface soil moisture and cause the water table to drop, reducing habitat suitability for phreatophytic vegetation and potentially causing springs to dry up (Karuk DNR 2009; Halpern et al. 2010).

Adaptive Capacity

Seeps and springs were evaluated by regional experts as having moderate overall adaptive capacity (moderate confidence in evaluation).

Habitat extent, integrity, continuity, and permeability

Regional experts evaluated seeps and springs as having a moderate geographic extent (moderate confidence in evaluation), moderate-high structural and functional integrity (moderate confidence), and low continuity (moderate confidence). Landscape permeability for seeps and springs was evaluated as high (moderate confidence), and no barriers to habitat continuity and dispersal were identified.

Seeps and springs are distributed widely but unevenly throughout California (Howard & Merrifield 2010). The North Coast and North Coast Range has some of the most dense occurrences of springs in the state (Howard & Merrifield 2010), while the Sacramento River watershed is supported by a complex of large springs that sustain the Sacramento, McCloud, and Pit Rivers and their major tributaries (Vuln. Assessment Reviewer, pers. comm., 2019).

Seep and spring ecosystems are often isolated (Howard & Merrifield 2010), reducing the potential for associated flora and fauna to shift their range in response to climate change (Schierenbeck 2017). Additionally, the integrity of some systems has been threatened by groundwater depletion, pollution, and other anthropogenic impacts (Springer & Stevens 2009).

Habitat diversity

Regional experts evaluated seeps and springs as having moderate-high physical and topographical diversity (moderate confidence in evaluation), moderate-high component species diversity (moderate confidence), and moderate-high functional diversity (moderate confidence).

Due to their high environmental stability and highly varied chemical composition, seep and spring ecosystems typically have high biodiversity and support many rare/endemic species and unique species assemblages (van der Kamp 1995; Virtanen et al. 2009). For example, the insectivorous California pitcher plant is associated with seeps within xeric serpentine landscapes of the Klamath Mountains, often with other rare plants and animals (CNPS 2019). A range of mammals, fish, insects, and amphibians also utilize seeps and springs. The rare Port Arena mountain beaver (*Aplodontia rufa nigra*) often locates its burrows in areas of seepage or springs on north-facing slopes, and running water within their burrow system may be a habitat requirement (Williams 1986). Springsnails, which are require coldwater springs with cobble substrates (Frest & Johannes 1999), are also a species of conservation concern in this habitat (Hershler et al. 2014). Cool spring water also feeds rivers, streams, and wetlands, increasing spawning and rearing habitat suitability for salmonids and providing coldwater refugia for many temperature-sensitive species (Ebersole et al. 2001; Fullerton et al. 2018).

Resistance and recovery

Regional experts evaluated seeps and springs as having moderate resistance to climate stressors and natural disturbance regimes (moderate confidence in evaluation). Recovery potential was evaluated as moderate (moderate confidence).

In general, seeps and springs associated with deep aquifers are more resistant to temperature and hydraulic flow changes than those reliant on shallow, unconfined aquifers (Healy & Cook 2002; Kløve et al. 2014; Huntington et al. 2016). However, climate-driven increases in groundwater withdrawals during dry periods can cause more rapid depletion than would otherwise occur (Huntington et al. 2016; Russo & Lall 2017). Additionally, deep and/or confined aquifers are more likely to contain non-renewable groundwater, which is particularly vulnerable to anthropogenic withdrawals (Treidel et al. 2011; Wada et al. 2012).

Management potential

Public and societal value

Regional experts evaluated seeps and springs as having low-moderate public and societal value (moderate confidence in evaluation).

Groundwater-dependent systems have high conservation value throughout western North America (Dwire et al. 2018). Groundwater is a diminishing resource in California, and current groundwater regulations often do not protect seep and spring ecosystems because they are primarily focused on sustaining water supplies for human use (Howard & Merrifield 2010). However, California passed the Sustainable Groundwater Management Act (Cal. Code Regs. 23 § 350–358) in 2014, which prompts the California Department of Water Resources to develop regulations that officially recognize groundwater-dependent ecological communities. This framework supports seep and spring preservation efforts by decreasing groundwater withdrawal and use for irrigation and relocating wells that affect recharge for these systems (Treidel et al. 2011).

Management capacity and ability to alleviate impacts[7]

Regional experts evaluated the potential for reducing climate impacts on seeps and springs through management as low (moderate confidence in evaluation).

Protection and management of seeps and springs are hindered by significant knowledge gaps, in part because they vary widely in type and geographic location (Howard & Merrifield 2010; Dwire et al. 2018). Identifying and monitoring seep and spring ecosystems would allow use of adaptive management strategies designed to protect groundwater supplies and critical habitat for the many rare and endemic species that utilize these areas (Howard & Merrifield 2010; Thomas & Famiglietti 2019). Incorporating climate change impacts into groundwater management will also help refine and prioritize current management practices in and around seeps and springs (Peterson & Halofsky 2018).

The scientific literature suggests multiple opportunities to adjust land-use practices and reduce non-climate impacts on seep and spring ecosystems. These include reducing anthropogenic groundwater withdrawals (Russo & Lall 2017; Thomas & Famiglietti 2019), reintroducing beaver to improve landscape water storage and groundwater recharge (Baldwin 2015; Dwire et al. 2018; Fesenmyer et al. 2018; Silverman et al. 2019), managing grazing intensity through fencing or alternative grazing approaches (Wyman et al. 2006; Swanson et al. 2015; Dwire et al. 2018), and providing guidance for timber harvest and forest management activities (e.g., fuel reduction) to lessen impacts on seeps and springs (Arkle & Pilliod 2010; Dwire et al. 2016).

Ecosystem services

Seeps and springs provide a variety of ecosystem services, including:

- Provisioning of fresh water;

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[7] Further information on climate adaptation strategies and actions for northern California can be found on the project page (https://bit.ly/31AUGs5).

- Regulation of water quality;
- Support of water cycling; and
- Cultural/tribal uses for spiritual/religious purposes, aesthetic values, cultural heritage, and inspiration (Vuln. Assessment Workshop, pers. comm., 2017).

Seep and spring ecosystems may also provide climate refugia for plants and animals as surrounding upland habitats become progressively warmer and drier (Olson et al. 2012).

Recommended Citation

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Further information on the Northern California Climate Adaptation Project is available on the project website (https://tinyurl.com/NorCalAdaptation).

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Defining Terms

Exposure: A measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011).

Sensitivity: A measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011).

Adaptive Capacity: The ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability: A function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2007).

Vulnerability Assessment Model

The vulnerability assessment model applied in this process was developed by EcoAdapt (EcoAdapt 2014a; EcoAdapt 2014b; Kershner 2014; Hutto et al. 2015; Gregg 2018),[8] and includes evaluations of relative vulnerability by local and regional stakeholders who have detailed knowledge about and/or expertise in the ecology, management, and threats to focal habitats, species groups, individual species, and the ecosystem services that these resources provide. Stakeholders evaluated vulnerability for each resource by discussing and answering a series of questions for sensitivity and adaptive capacity. Exposure was evaluated by EcoAdapt using projected future climate changes from the scientific literature. Each vulnerability component (i.e., sensitivity, adaptive capacity, and exposure) was divided into specific elements. For example, habitats included three elements for assessing sensitivity and six elements for adaptive capacity. Elements for each vulnerability component are described in more detail below.

In-person workshops were held in Eureka, Redding, and Upper Lake between May and October 2017. Participants self-selected habitat and species group/species breakout groups and evaluated the vulnerability of each resource. Participants were first asked to describe the habitat and/or to list the species to be considered in the evaluation of an overarching species group. Due to limitations in workshop time and participant expertise, multiple resources were not assessed during these engagements. Evaluations for remaining habitats, species groups, and species were completed by contacting resource experts.[9]

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[8] Sensitivity and adaptive capacity elements were informed by Lawler 2010, Glick et al. 2011, and Manomet Center for Conservation Sciences 2012.

[9] Resources evaluated by experts included: coastal bluff/scrub habitats, coastal conifer hardwood forest, true fir forest, lakes/ponds, freshwater marshes, vernal pools, seeps/springs, native insect pollinators, native ungulates, salamanders, frogs, native mussels, marbled murrelet, and northwestern pond turtle.

Stakeholders assigned one of five rankings (High, Moderate-High, Moderate, Low-Moderate, or Low) for sensitivity and adaptive capacity. EcoAdapt assigned rankings for projected future climate exposure. Rankings for each component were then converted into scores (High-5, Moderate-High-4, Moderate-3, Low-Moderate-2, or Low-1), and the scores were averaged (mean) to generate an overall score. For example, scores for each element of habitat sensitivity were averaged to generate an overall habitat sensitivity score. Scores for exposure were weighted less than scores for sensitivity and adaptive capacity because the uncertainty about the magnitude and rate of future change is greater. Sensitivity, adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as:

Vulnerability = [(Climate Exposure*0.5) x Sensitivity] - Adaptive Capacity

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). Confidence rankings were converted into scores (High-3, Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall confidence score. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2012) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report. The vulnerability assessment model applied here assesses the confidence associated with individual element rankings and, from these rankings, estimates the overall level of confidence for each component of vulnerability and then for overall vulnerability.

Stakeholders and decision-makers can consider the rankings and scores presented as measures of relative vulnerability and confidence to compare the level of vulnerability among the focal resources evaluated in this project. Elements that received lower confidence rankings indicate knowledge gaps that applied scientific research could help address.

Vulnerability Assessment Model Elements

Sensitivity & Exposure (Applies to Habitats, Species Groups, Species)

- **Climate and Climate-Driven Factors:** e.g., air temperature, precipitation, freshwater temperature, soil moisture, snowpack, extreme events: drought, altered streamflows, etc.
- **Disturbance Regimes:** e.g., wildfire, flooding, drought, insect and disease outbreaks, wind
- **Future Climate Exposure:** e.g., consideration of projected future climate changes (e.g., temperature and precipitation) as well as climate-driven changes (e.g., altered fire regimes, altered water flow regimes, shifts in vegetation types)
- **Stressors Not Related to Climate:** e.g., tectonic and volcanic events; residential or commercial development; agriculture and/or aquaculture; roads, highways, trails; dams and water diversions; invasive and other problematic species; livestock grazing; fire suppression; timber harvest; mining; etc.

Sensitivity & Exposure (Applies to Species Groups and Species)

- **Dependencies:** e.g., dependencies on sensitive habitats, specific prey or forage species, and the timing of the appearance of these prey and forage species (concern for mismatch)

Sensitivity & Exposure (Applies to Species ONLY)

- **Life History:** e.g., species reproductive strategy, average length of time to reproductive maturity

Adaptive Capacity (Applies to Habitats, Species Groups, Species)

- **Extent, Integrity, and Continuity/Connectivity:** e.g., resources that are widespread vs. limited, structural and functional integrity (e.g., degraded or pristine) of a habitat or health and functional integrity of species (e.g., endangered), isolated vs. continuous distribution
- **Landscape Permeability:** e.g., barriers to dispersal and/or continuity (e.g., land-use conversion, energy production, roads, timber harvest, etc.)
- **Resistance and Recovery:** e.g., *resistance* refers to the stasis of a resource in the face of change, *recovery* refers to the ability to "bounce back" more quickly from the impact of stressors once they occur
- **Management Potential:** e.g., ability to alter the adaptive capacity and resilience of a resource to climatic and non-climate stressors (societal value, ability to alleviate impacts, capacity to cope with impacts)
- **Ecosystem Services:** e.g., provisioning, regulating, supporting, and/or cultural services that a resource produces for human well-being

Adaptive Capacity (Applies to Habitats ONLY)

- **Habitat Diversity:** e.g., diversity of physical/topographical characteristics, component native species and functional groups

Adaptive Capacity (Applies to Species Groups, Species)

- **Dispersal Ability**: i.e., ability of a species to shift its distribution across the landscape as the climate changes
- **Intraspecific/Life History Diversity:** e.g., life history diversity, genetic diversity, phenotypic and behavioral plasticity

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