Focal Resource: AMERICAN MARTEN

Taxonomy and Related Information

Marten (*Martes americana*); occurs across the Sierra Nevada but more common in the central and southern Sierra Nevada.

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop[1]. The following document represents the vulnerability assessment results for the **AMERICAN MARTEN**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The aim of this synthesis is to expand understanding of resource vulnerability to changing climate conditions, and to provide a basis for developing appropriate adaptation responses. The resulting document is an initial evaluation of vulnerability based on existing information and expert input. Users are encouraged to refer to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO, http://www.taccimo.sgcp.ncsu.edu/) website for the most current peer-reviewed literature on a particular resource. This synthesis is a living document that can be revised and expanded upon as new information becomes available.

Geographic Scope

The project centers on the Sierra Nevada region of California, from foothills to crests, encompassing ten national forests and two national parks. Three geographic sub-regions were identified: north, central, and south. The north sub-region includes Modoc, Lassen, and Plumas National Forests; the central sub-region includes Tahoe, Eldorado, and Stanislaus National Forests, the Lake Tahoe Basin Management Unit, and Yosemite National Park; and the south sub-region includes Humboldt-Toiyabe, Sierra, Sequoia, and Inyo National Forests, and Kings Canyon/Sequoia National Park.

Key Definitions

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption[2].

Sensitivity: A measure of whether and how a species or system is likely to be affected by a given change in climate or factors driven by climate.

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[1] For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at: http://ecoadapt.org/programs/adaptation-consultations/calcc.

[2] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Adaptive Capacity: The degree to which a species or system can change or respond to address climate impacts.

Exposure: The magnitude of the change in climate or climate driven factors that the species or system will likely experience.

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation[3]. For more information on each of these elements of sensitivity, adaptive capacity, and exposure, including how and why they were selected, please refer to the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[4].

During the workshop, participants assigned one of three rankings (High (>70%), Moderate, or Low (<30%)) to each finer resolution element and provided a corresponding confidence score (e.g., High, Moderate, or Low) to the ranking. These individual rankings and confidence scores were then averaged (mean) to generate rankings and confidence scores for each vulnerability component (i.e., sensitivity, adaptive capacity, exposure score) (see table below). Results presented in a range (e.g. from moderate to high) reflect variability assessed by participants. Additional information on ranking and overall scoring can be found in the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[4].

Recommended Citation

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[3] Geos Institute. 2013. *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis report in support of the Vulnerability Assessment/Adaptation Strategy process.* Ashland, OR. http://ecoadapt.org/programs/adaptation-consultations/calcc.

[4] Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada.* Version 1.0. EcoAdapt, Bainbridge Island, WA. http://ecoadapt.org/programs/adaptation-consultations/calcc.

This document is available online at EcoAdapt (http://ecoadapt.org/programs/adaptation-consultations/calcc).

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Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	**2 Between generalist & specialist**	**3 High**
Physiology	**2 Moderate**	**1 Low**
Habitat	**3 High**	**2.5 Moderate-High**
Life History	**3 High**	**3 High**
Ecological Relationships	**3 High**	**2 Moderate**
Disturbance Regimes	**3 High**	**2.5 Moderate-High**
Non-Climatic Stressors – Current Impact	**2 Moderate**	**2.5 Moderate-High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**3 High**	**2.5 Moderate-High**
Other Sensitivities	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Sensitivity)[5]: Moderate

Overall Averaged Ranking (Sensitivity)[6]: Moderate–High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**2 Moderate**	**2 Moderate**
Barriers Affect Dispersal Ability	**2.5 Moderate-High**	**2.5 Moderate-High**
Plasticity	**2 Moderate**	**1.5 Low-Moderate**
Evolutionary Potential	**2 Moderate**	**2 Moderate**
Intraspecific Diversity/Life History	**2 Moderate**	**2 Moderate**
Species Value	**3 High**	**3 High**
Specificity of Management Rules	**1.5 Low-Moderate**	**2.5 Moderate-High**
Other Adaptive Capacities	**No answer provided by participants**	**No answer provided by participants**

Overall Averaged Confidence (Adaptive Capacity)[5]: Moderate

Overall Averaged Ranking (Adaptive Capacity)[6]: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**2 Moderate**
Precipitation	**2 Moderate**
Shifts in vegetation structure	**1.5 Low-Moderate**
Wildfire	**2 Moderate**
Snowpack	**3 High**

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[5] Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

[6] Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**3 High**	**2 Moderate**
Central Sierra Nevada	**2.5 Moderate–High**	**2 Moderate**
Southern Sierra Nevada	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Exposure)[5]: Moderate

Overall Averaged Ranking (Exposure)[6]: Moderate–High

Sensitivity

1. **Generalist/Specialist.**
    a. Where does species fall on spectrum of generalist to specialist: In between
        i. Participant confidence: High
    b. Factors that make the species more of a specialist: Predator/prey relationship, foraging dependency, other – snowpack

Additional comments: Marten range is restricted by snow conditions, prey availability, and competition with the fisher and great grey owl.

The marten is a diet generalist when considered year-round, but winter diet can be much more specific (e.g., snowshoe hares, flying squirrels, and voles). Two of the three prey species are very dependent on snow conditions and the maintenance of subnivean foraging opportunities or deep snow. Thus, the diet in the most vulnerable season – from a climate change perspective – is rather specialized and several of the species used as prey resources are dependent on snow conditions.

References: Marten prefer high-elevation (approximately 1400 m to 3000 m) (4593 ft to 9843 ft) (Purcell et al. 2012), late-successional mixed-conifer, and red fir forests for resting and denning (Verner and Boss 1980, Meslow et al. 1981 cited in Spencer et al. 1983). Marten are highly selective of microhabitats, preferring complex structures near the ground, closed canopy (Slauson et al. 2007; Kirk and Zielinski 2009) and large diameter trees (Martin and Barrett 1991; Buskirk and Powell 1994; Slauson et al. 2007; Kirk and Zielinski 2009). For example, snags, stumps, and logs made up 61% of resting sites found near Sagehen Creek in Tahoe National Forest, and tree canopy accounted for another 13% of resting sites (Martin and Barrett 1991). Snag diameters averaged 43.9 cm (17.3 in), stump diameters averaged 83 cm (32.7 in), and log diameters averaged 69.4 cm (27.3 in) (Martin and Barrett 1991). Martens do not persist in forest systems where >30% of the original forest cover has been removed (Bissonette et al. 1997; Chapin et al. 1998; Hargis et al. 1999; Potvin et al. 2000).

Overall marten exhibit a generalist annual diet (Zielinski and Duncan 2004), however, winter diet of marten is specialized to a few accessible or abundant prey items, many of which rely on deep snow for subnivean foraging and caching opportunities (Grinnell et al. 1937, Marshall 1946, Cowan and Mackay 1950, Weckwerth and Hawley 1962, Francis and Stephenson 1972, and Soutiere 1979 cited in Zielinski et al. 1983; Zielinski and Duncan 2004). In winter, as subnivean dens and cone caches begin to be used by larger animals, martens appears to switch to larger prey, which likely representing a greater energy gain per capture (Zielinski et al. 1983). Winter prey includes voles (*Microtus spp*.), Douglas squirrels (*Tamiasciurus douglasii*), snowshoe hares (*Lepus americanus*), and flying squirrels (*Glaucomys sabrinus*) (Zielinski et al. 1983). Because marten requires thermal cover provided by snow in subalpine and montane habitats during winter (Buskirk et al. 1989, Taylor and Buskirk 1994 cited in Halofsky et al. 2011), changes in the structure and quality of the subnivean environment due to reduced snowpack (Pauli et al. 2013) could expose the marten to lethally cold temperatures (Halofsky et al. 2011).

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2. **Physiology.**
    a. Species physiologically sensitive to one or more factors including: Temperature, precipitation, other – snow
    b. Sensitivity of species' physiology to one or more factors: Moderate
        i. Participant confidence: Low

Additional comments: Species is reproductively sensitive to the factors listed above, not physiologically sensitive.

3. **Sensitive habitats.**
    a. Species dependent on sensitive habitats including: Other – snowpack, limited number of competitors
    b. Species dependence on one or more sensitive habitat types: High
        i. Participant confidence: Moderate-High

Additional comments: The marten requires winter snowpack for reproductive success.

References: Martens rely on thick snowpack to exclude predators, provide high-quality hunting conditions, and provide winter resting and denning sites (Martin and Barrett 1991; Buskirk and Powell 1994; Bull and Heater 2000). Winter diet includes a few dominant species, most of which rely on subnivean conditions or deep snow to prosper, thus winter diet may be considered rather specialized (Zielinski et al. 1983). Furthermore, because the marten requires thermal cover provided by snow in subalpine and montane habitats during winter, reduced snowpack could expose the marten to lethally cold temperatures (Halofsky et al. 2011).

4. **Life history.**
    a. Species reproductive strategy: K-selection
        i. Participant confidence: High
    b. Species polycyclic, iteroparous, or semelparous: Iteroparous

Additional comments: Marten bears kits each year.

5. **Ecological relationships.**
    a. Sensitivity of species' ecological relationships to climate change including: Predator/prey relationship, competition
    b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation, other – snow
    c. Sensitivity of species to other effects of climate change on its ecology: High
        i. Participant confidence: Moderate

Additional comments: Climate change may intensify interspecific competition and prey availability might no longer be sufficient.

Deep snow gives marten a competitive advantage over fishers due to higher foot loading of martens (i.e., better "snowshoes"). Thus, decreasing snow – or snow period – will give an edge to fishers, as will the habitat changes expected in the Sierra.

References: The subnivean environment provides stable temperatures, and decreased snowpack is expected to result in colder and more thermally variable subnivean space, despite warming winter temperatures (Pauli et al. 2013), potentially affecting both marten and prey species. Colder and more variable temperatures within the subnivean space may have major impacts on mammal communities that have evolved under these mild and stable subnivean conditions (Pauli et al. 2013). Marten have a competitive advantage over fisher in deep snow, due to higher foot loading in marten; decreasing snowpack may remove this advantage and benefit fishers, potentially altering marten and fisher spatial distributions (Krohn et al. 1997).

6. **Disturbance regimes.**

   a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, insects, disease
   b. Sensitivity of species to one or more disturbance regimes: High
      i. Participant confidence: Moderate-High

Additional comments: Severe wildfire is negative in the short-term because marten require logs, large woody debris, shrubs, and downed snags as habitat for foraging, resting, and denning. In the long term, wind and the other disturbance factors may provide additional habitat by providing more downed trees.

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7. **Interacting non-climatic stressors.**
   a. Other stressors that make the species more sensitive include: Altered interspecific interactions, pollution and poisons, other – large openings
   b. Current degree to which stressors affect the species: Moderate
      i. Participant confidence: Moderate-High
   c. Degree to which non-climate stressors make species more sensitive: High
      i. Participant confidence: Moderate-High

Additional comments: Marten may be susceptible to poisons such as rodenticides if they are used at the elevations that marten occupy. Zielinski et al. 2008 suggest that martens tolerate snowmobile use and noise.

References: Martens are sensitive to disturbances that may limit habitat availability and quality (Kirk and Zielinski 2009; Slauson et al. 2007), including grazing pressure (Spencer et al. 1983), road density (Wasserman et al. 2010), timber harvest, and forest management practices (Zielinski et al. 2005). The distribution of mature forests may be the primary determinant of marten distribution (Kirk and Zielinski 2009).

Pesticides employed in illegal marijuana cultivations are known to cause mortality and decreased fitness in Pacific fishers, and may pose a risk to martens in the Sierra Nevada (Gabriel et al. 2012). Sublethal exposure to pesticides has been associated with reduced thermoregulatory capacity in birds and mice (Grue et al. 1991, Gordon 1994 cited in Thompson et al. 2013).

Martens appear to tolerate snowmobile noise (Zielinski et al. 2008).

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8. **Other sensitivities.**
   a. Other critical sensitivities not addressed: Large scale-high intensity fires
      i. Participant confidence: Moderate
   b. Collective degree these factors increase species' sensitivity to climate change: Moderate

References: Zielinski et al. 2008 suggest that martens tolerate snowmobile use and noise.

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9. **Overall user ranking.**
   a. Overall sensitivity of this species to climate change: High
      i. Participant confidence: Moderate-High

References: Please also refer to the following references on marten in California: Simon (1980), Spencer et al. (1983), Zielinski et al. (1983), Hargis and McCullough (1984), and Ellis (1998).

Adaptive Capacity

1. **Dispersal ability.**
    a. Maximum annual dispersal distance: >100 km (>62 mi)
        i. Participant confidence: High
    b. Ability of species to disperse: Moderate
        i. Participant confidence: Moderate
    c. General types of barriers to dispersal include: Road-highway, industrial or urban development, suburban or residential development, clear cut, arid lands
    d. Degree barriers affect dispersal for the species: Moderate-High
        i. Participant confidence: Moderate-High
    e. Possibility for individuals to seek out refugia: No answer provided by participants

Additional comments: The marten is a very mobile species. Potential impediments to dispersal include highways, residential developments, and clear-cut areas.

References: Distribution of martens has decreased since the early 1900s, and is fragmented in the southern Cascades and northern Sierra Nevada (Zielinski et al. 2005). The distribution of mature forests may be the primary determinant of marten distribution (Kirk and Zielinski 2009). Forest fragmentation may reduce marten numbers, and may influence fragmentation of population distribution (Phillips 1994; Zielinski et al. 2005; Kirk and Zielinski 2009). Martens do not persist in forest systems where >30% of the original forest cover has been removed (Bissonette et al. 1997; Chapin et al. 1998; Hargis et al. 1999; Potvin et al. 2000).

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2. **Plasticity.**
    a. Ability of species to modify physiology or behavior: Moderate
        i. Participant confidence: Low-Moderate
    b. Description of species' ability to modify physiology or behavior: The marten is very mobile and has a generalist annual diet, but has strict requirements of snow for reproduction.

References: In serpentine habitats in California, where large diameter trees and logs are largely absent, marten have been located in large rock structures with interstitial spaces, which may provide for the life-history needs that woody structures typically provide (Slauson et al. 2007). While martens have been documented using boulder fields, talus slopes, and rockslides in areas with reduced forest cover, those habitats may not provide for year-round habitat needs (Slauson et al. 2007; Green 2007 cited in Purcell et al. 2012).

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3. **Evolutionary potential.**
    a. Ability of species to adapt evolutionarily: Moderate
        i. Participant confidence: Moderate
    b. Description of characteristics that allow species to adapt evolutionarily: Lack of habitat connectivity may inhibit gene flow.

References: Distribution of martens has decreased since the early 1900s and is fragmented in the southern Cascades and northern Sierra Nevada (Zielinski et al. 2005). Moreover, dramatic reduction of habitat area will likely be accompanied by large decreases in local population size, increasing likelihood of local extinction (Wasserman et al. 2012). Climate change may shift suitable bioclimate conditions up the elevational gradient, reducing connectivity of important habitat for high elevation species (Wasserman et al. 2010), such as martens. Habitat patchiness and population isolation is predicted to genetically isolate the marten, reducing genetic allelic richness and expected heterozygosity (Wasserman et al. 2012). Inbreeding depression has been strongly linked to extinction risk and the loss of allelic diversity reduces evolutionary potential. In addition, dramatic reduction of habitat area will likely be accompanied by large decreases in local population size, increasing likelihood of local extinction (Wasserman et al. 2012).

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4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Moderate
  - i. Participant confidence: Moderate
- b. Description of diversity of life history strategies: The marten is mobile but has limited reproductive potential and ability to change reproduction.

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5. Management potential.

- a. Value level people ascribe to this species: High
  - i. Participant confidence: High
- b. Specificity of rules governing management of the species: Low-Moderate
  - i. Participant confidence: Low-Moderate
- c. Description of use conflicts: Recreation and water diversions.
- d. Potential for managing or alleviating climate impacts: The potential for managing or alleviating climate impacts is low. Focusing on habitat connectivity and water diversion considerations, such as those that allow wet meadows to be maintained, could improve adaptive capacity. Management actions could maintain or increase cover, naturally or artificially, in open areas.

References: The potential for management to alleviate climate impacts is low, and should focus on maintaining habitat connectivity, including dense shrub cover (Slauson et al. 2007).

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6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: No answer provided by participants
  - i. Participant confidence: No answer provided by participants
- b. Collective degree these factors affect the adaptive capacity of the species: No answer provided by participants

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7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate
  - i. Participant confidence: Moderate

Exposure

1. **Exposure factors[7].**
    a. <u>Factors likely to be most relevant or important to consider for the species</u>: Temperature, precipitation, shifts in vegetation, wildfire, snowpack
        i. Participant confidence: Moderate (temperature), Moderate (precipitation), Low-Moderate (shifts in vegetation), Moderate (wildfire), High (snowpack)

2. **Exposure region.**
    a. <u>Exposure by region:</u> North – High; Central – Moderate-High; South – Moderate
        i. Participant confidence: Moderate (all)

3. **Overall user ranking.**
    a. <u>Overall exposure of the species to climate changes</u>: High
        i. Participant confidence: Moderate-High

Additional comments: Participants are unsure how flexible the species will be in the future.

References: Please see the book <u>Martens and fishers in a changing climate</u> by Lawler et al. (2012) for climate impacts on marten.

<u>Vegetation and habitat changes:</u> In the Sierra Nevada, a shift in distribution to higher elevations could drive martens toward the limit of forested habitats, potentially limiting their distribution and leading to decreases in population size. Models suggest that increased temperature as a result of climate change and an increase in plant fuel could augment both the severity and frequency of fire, potentially leading to vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008) important for marten habitat. Loss of red fir/lodgepole communities in the Sierra Nevada may be accelerated by changes in the severity and frequency of fire (PRBO Conservation Science 2011), although increased fire may create opportunities to expand for some component species, such as lodgepole pine (Bartlein et al. 1997). Climate change may also reduce the connectivity of dispersal habitat for the marten and fisher (Wasserman et al. 2010), resulting in predicted genetic isolation, reduced genetic allelic richness and expected heterozygosity, and increased risk of local extinction (Wasserman et al. 2012).

<u>Temperature</u>: Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004: Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL[8] and PCM[9]) predict summer temperatures to increase 1.6-2.4˚C by mid- century (2049), with the least increases expected in the northern bioregion, and greatest increases expected in the southern bioregion (Geos Institute 2013). By late century (2079), summer temperatures are forecast to increase 2.5-4.0˚C, with changes of least

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[7] Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

[8] Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. Journal of Climate, 19:643-674.

[9] Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. Climate Dynamics 16:755-744.

magnitude occurring in the central bioregion (Geos Institute 2013). Winter temperatures are forecast to increase 2.2-2.9˚C by late century (2079), with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Precipitation: Precipitation has increased slightly (~2%) in the Sierra Nevada over the past 30 years compared with a mid-twentieth century baseline (1951-1980) (Flint et al. 2013). Projections for future precipitation in the Sierra Nevada vary among models; some demonstrate little to no change (e.g. PCM) while others demonstrate more substantial changes (e.g. GFDL). In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004b; Young et al. 2009; Null et al. 2010).

Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (2060-2079) (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013). Under scenarios of 2-6˚C warming, snowpack is projected to decline 10-25% at elevations above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). Several models project greatest losses in snowmelt volume between 1750 m to 2750 m (5741 ft to 9022 ft) (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009), because snowfall is comparatively light below that elevation, and above that elevation, snowpack is projected to be largely retained. The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012), with the current patterns of snowpack retention in higher-elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007).

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5˚C warming (Dettinger et al. 2004b). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006). A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds (Null et al. 2010). Decreases in winter precipitation combined with increases in summer temperature may produce declines in conifer tree growth in mixed conifer forest of northern California (Yeh and Wensel 2000).

Wildfire: Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Increasing temperatures and earlier snowmelt in the Sierra Nevada have been correlated with an increase in large (>1000 acre or >404 ha) extent fire since the 1980s (Westerling and Bryant 2006). Between 1972-2003, years with early arrival of spring conditions accounted for 56% of wildfires and 72% of area burned in the western U.S., as opposed to 11% of wildfires and 4% of area burned in years with a late spring (Westerling et al. 2006; Geos Institute 2013). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) from 1984-2007, especially in middle elevation conifer forests (Miller et al. 2009).

Fire activity within the Sierra Nevada is influenced by distinct climate patterns and diverse topography. Higher fire activity is weakly associated with El Niño (warm) conditions in parts of the southern Cascades (Taylor et al. 2008) and northern Sierra Nevada (Valliant and Stephens 2009 cited in Taylor and Scholl 2012), while in Yosemite National Park (YNP) large fires are associated with La Niña (cool) conditions, which are characteristically drier (Taylor and Scholl 2012). Some evidence suggests that fire frequency is higher on southern aspect than northern aspect slopes in mid- and upper-montane forests (Taylor 2000); however, in YNP mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010). Burn condition heterogeneity may promote different forest understory responses in mixed conifer forests across a landscape, with lower intensity burns promoting tree regeneration, and higher intensity or more frequent burns creating shrub habitat (Lydersen and North 2012).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that "heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales" (Taylor and Scholl 2012).

Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011). Models suggest that the increase in fuel and temperature could increase both the severity and frequency of fire, potentially leading to vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the species may be found through the TACCIMO website (http://www.sgcp.ncsu.edu:8090/). Downscaled climate projections available through the Data Basin website (http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52).

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