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Response of *Arnica dealbata* to climate change, nitrogen deposition, and fire

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Abstract Predicted changes in climate and increasing nitrogen deposition are likely to have significant impacts on species that have limited distributions or are already experiencing diminished population size. *Arnica dealbata* (A. Gray, Asteraceae), a listed sensitive species in Yosemite National Park, is endemic to California and has limited distribution within the park boundaries. The objective of this research was to examine the effects of altered precipitation resulting from climate change, increasing nitrogen deposition resulting from pollution, and prescribed fire on *A. dealbata*. *A. dealbata* cover significantly increased with increasing snowpack and prescribed fire. Increasing nitrogen deposition negatively affected cover. Our results suggest Yosemite's *A. dealbata* populations can thrive even under a changing climate if prescribed fire is frequently applied coupled with increased moisture availability.

Keywords Climate change · Mixed-conifer · Sierra Nevada

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Introduction

California's Sierra Nevada mountain range is expected to experience altered precipitation regimes as a result of changing climatic conditions (Cayan et al. 2008; Field et al. 1999). Commensurate with these changes in precipitation is an expected increase in nitrogen deposition resulting in part from fossil fuel consumption (Fenn et al. 2003). These changes occur as land managers attempt to restore fire into forests that have experienced a century or more of fire suppression. Regional predictions for the Sierra Nevada Mountains include an increase in late winter/early spring precipitation, in conjunction with hotter, drier summers (Cayan et al. 2008; Field et al. 1999; Hayhoe et al. 2004). These predicted changes in weather are likely to lead to increased fire frequency and intensity (Miller and Urban 1999), making the restoration of pre-suppression fire regimes essential for reducing catastrophic fire risk.

Changing climatic conditions pose a substantial risk to threatened species and species with limited geographic ranges (Harris et al. 2006). In a study to determine the impacts of altered precipitation, increasing nitrogen, and fire on Sierran mixed-conifer forest understory (Hurteau and North 2008), we increased and decreased snowpack, increased nitrogen, and applied prescribed fire in a full factorial design to 72 plots at two locations. In the Crane Flat area of Yosemite National Park (the northern location), we identified *Arnica dealbata*, a park sensitive species endemic to California, on our plots.

Predicted increases in the two most limiting resources in Sierran mixed-conifer forest, water and nitrogen (Fenn et al. 1998; Witty et al. 2003), have the potential to affect the understory plant community and further exacerbate the fire threat by increasing forest understory fuels. Several studies have been conducted to identify the impacts of climate change and nitrogen enrichment on plant communities and have found that increasing precipitation results in increased biomass production and/or net primary productivity (Grime et al. 2000; Shaw et al. 2002) and increasing nitrogen deposition results in decreased species richness (Zavaleta et al. 2003). Determining how the predicted climate scenarios will influence rare species such as *A. dealbata* is important for allowing land managers to make informed decisions.

Arnica dealbata was listed as a park sensitive species in 1984 because it is believed to occur in only two places within the park and be uncommon throughout its range (Peggy Moore, personal communication). Previously classified as *Whitneya dealbata*, *A. dealbata* was reclassified by Baldwin (1999) to make it monophyletic. One of the goals of this research was to determine the effects of fire management on this species. Specifically, we wanted to determine if fire would increase the abundance of this rhizomatous species. Additionally, we wanted to determine how the species would respond to the suite of possible future conditions that we tested in the experiment.

Methods

Our study was conducted in mixed-conifer forest at Yosemite National Park (2,100 m elevation), which had five principal overstory species: *Abies concolor*, *Abies magnifica*, *Calocedrus decurrens*, *Pinus jeffreyi*, and *Pinus lambertiana*.

We used a 3 × 2 × 2 full factorial design, with three replicates per treatment. The treatments included increased and decreased snowpack by 60% of average (applied in March each year), increased nitrogen (NH_4) by the equivalent of 12 kg/ha/year (hand spread in May each year), and prescribed fire. We chose ammonia over nitrate because of its availability to plants and the relatively short duration of the study. The 36 plots were established and a pre-treatment measurement was made in 2003. Snow and nitrogen treatments were applied in 2004–2006. Prescribed fire was applied in the summer of 2005 and post-treatment measurements were made during the summer of 2006. During the growing season, each 9 × 9 m plot was subdivided into nine subplots and surveyed in its entirety for percent cover by species using a 1 × 1 m quadrat.

We examined treatment effects on *A. dealbata* percent cover. We used repeated measures ANOVA in SAS with a least-squares difference (LSD) mean separation for the main effects and a Tukey adjusted least-squares means for the interaction effects. We considered results to have biological significance if $P \leq 0.05$.

Results and discussion

The significant interaction effects indicate a complex response depending on the particular treatment level combination (Table 1). The snowpack increase ($\mu = 48.3\%$) resulted in significantly higher cover values than the snowpack decrease ($\mu = 5.2\%$) ($P < 0.0001$, $F_{2,14} = 49.64$). While not statistically significant, the snowpack increase also resulted in higher cover values than the ambient snowpack ($\mu = 24.6\%$). This may be due to *A. dealbata*'s association with meadows and open forests (Hickman 1993), where more precipitation tends to reach the surface rather than being intercepted by overstory tree canopies. The nitrogen increase ($\mu = 10.2\%$) treatment was not statistically significant, but did result in lower cover than the ambient treatment

Table 1 ANOVA table results from split-plot analysis for repeated measurements

Source	df	Type III SS	Mean square	*F*-value	*P*-value
Snow	2	32014.9	16007.4	49.64	<0.0001
Nitrogen	1	2508.3	2508.3	7.78	0.0063
Fire	1	1799.1	1799.1	5.58	0.02
Snow * Nitrogen	2	3644.0	1822.0	5.65	0.0046
Snow * Fire	2	8639.2	4319.6	13.39	<0.0001
Nitrogen * Fire	1	2889.0	2889.0	8.96	0.0034
S * N * F	2	1018.7	509.3	1.58	0.2108
Rep * S * N * F	14	71586.8	5113.3	15.86	<0.0001

($\mu = 24.6\%$). The response to nitrogen treatments may be a function of our application of ammonia rather than nitrate, which comprises a larger proportion of dry deposition. However, other species such as *Kellogia gallioides* did experience a positive growth response to the ammonia application (Hurteau and North 2008). The sparse distribution of *A. dealbata* may make it less able to compete with species that capitalized on the nitrogen addition treatments.

The fire treatment independently ($\mu = 3.5\%$), while not statistically significant, did result in lower cover than the ambient treatment. This was surprising since many rhizomatous species are adapted to frequent fire regimes, readily re-sprouting from dormant sub-surface buds or tubers, which can survive moderately high temperatures (Brown and Smith 2000). With the exception of the ambient treatment, the snowpack increase, snowpack increase + fire, and snowpack increase + nitrogen + fire treatments all resulted in significantly greater cover than the other treatments (Fig. 1). The increase in cover following nitrogen's addition in the snowpack increase + nitrogen + fire treatment may be because this treatment increased the burn's severity and extent (Hurteau and North 2008), which when coupled with increased snowpack, favored *A. dealbata*'s re-sprouting.

Current Sierran mixed-conifer forest conditions are outside of their historic range of variability. Prior to fire suppression, mixed conifer had an open structure and experienced more frequent, low-severity surface fires (North et al. 2007). Our findings have several important implications for managing *A. dealbata*. Reintroducing prescribed fire alone may not positively influence the species. *A. dealbata* is usually associated with open forest conditions. We also found higher cover when an increase in snowpack was followed by prescribed fire. These results suggest that in the near-term, managers should consider increasing moisture availability by decreasing overstory canopy cover, which would decrease precipitation interception. In the long-term, specific management actions should depend upon the climate change scenario that unfolds. Under a range of modeled greenhouse gas concentrations, Lenihan et al. (2008) found that the area burned in California is likely to increase. If a general increasing trend in precipitation occurs, fire could be a useful tool for maintaining *A. dealbata*. However, if a general decreasing trend in precipitation occurs, *A. dealbata* abundance may diminish further. Regardless of the trend in precipitation, a prudent hedge against uncertainty for *A. dealbata* would be managing for increased soil moisture availability by restoring a more open historic forest condition.

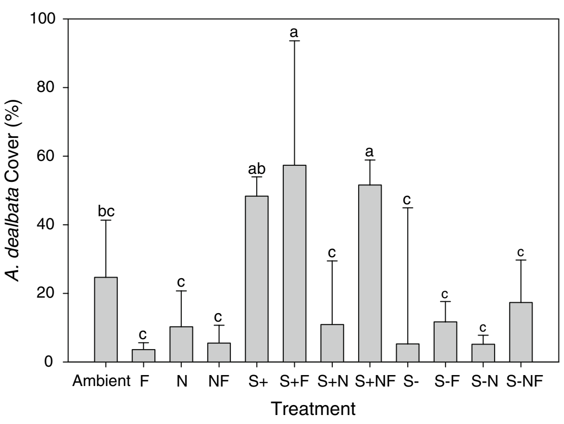

Fig. 1 Mean percent cover response of *A. dealbata* to treatments F, fire; N, nitrogen; S, snowpack; +/−, snowpack increase/decrease. Treatments with different letters are significantly different

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