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Life along an elevation gradient: The effects of elevation on the invasiveness of *Linaria dalmatica*

Mountain areas throughout the world are much less inundated with non-native plant species than lowland areas. However, increased human use of mountain areas and the potential effects of global climate change may increase non-native plant frequency in high elevation systems. Invasion is primarily limited by population demographics and/or dispersal. The degree to which these processes contribute to invasion along an elevation gradient was the focus of this study. The study was initiated in Summer 2008 to determine the effects of elevation on the growth and reproductive output of the non-native species *Linaria dalmatica* along three mountain roads in the Absaroka-Beartooth Range (MT and WY) and the Northern Range of Yellowstone National Park (WY). The roads commenced at approximately 1700 m elevation and in all cases the upper elevation extents of the road were higher than the highest known *L. dalmatica* populations. Data on stem density, stem height, capsule and seed production, and seed germination were collected from eighteen *L. dalmatica* populations. Stem height, stem density, and capsule production all showed a unimodal trend, with a peak at the middle of the elevation gradient and decreases toward either end of the gradient ($p < 0.05$). This indicates that *L. dalmatica* is adversely affected from the middle to both the high and low ends of the elevation gradient by changing environmental conditions, and that the species is currently limited from expanding to higher elevations by more than a lack of dispersal opportunities.

# Life along an elevation gradient: The effects of elevation on the invasiveness of *Linaria dalmatica*

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## Introduction

Mountainous areas contain about 1/3 of the total terrestrial plant diversity on the planet[1]. In general, mountainous areas are not as heavily invaded by non-indigenous plant species (NIS) as their lowland counterparts[2]. However, these areas will become increasingly threatened by NIS invasions due to increased use of mountain areas by humans[3,4] and climate change[4].

In the past, mountainous areas have been viewed as pristine, and perhaps resistant to NIS invasions due to harsh climatic conditions[5]. However, over 1,000 NIS have been recorded in mountain areas worldwide[2] and it is clear that a better understanding of the dynamics of NIS invasions into mountain areas is required to help protect them from future invasions, and to help limit invasions in progress.

Numerous studies have shown that NIS richness decreases with increased elevation throughout the world[2]. However, the reasons for this trend are unclear. This may be due to fewer opportunities to establish at higher elevations (lower propagule supply[6], less time since introduction[4], less disturbance[7], or simply less land area to colonize[8]), or to the inability of NIS to establish due to more harsh conditions at higher elevations. To better understand this phenomenon, the responses of individual NIS must be measured along elevation gradients to determine if their current ranges are dictated by opportunity, ability, or a combination of both. This information will be of critical importance to land managers in these areas in that it will provide an improved understanding of how to proceed with management of NIS within their current ranges, and if/how NIS ranges may shift as a result of future climate change.


Adult *L. dalmatica* in flower.

Approximate location of study area.


Collecting data from a *L. dalmatica* plot in the field.


Close up of mature seed capsule on adult *L. dalmatica* plant.

## *Linaria dalmatica*

- Established in many regions of the Greater Yellowstone Ecosystem (GYE)
- Historically introduced within the study area just above lowest point on the observed elevation gradients
- Short lived perennial
- Reproduces via seeds and vegetatively

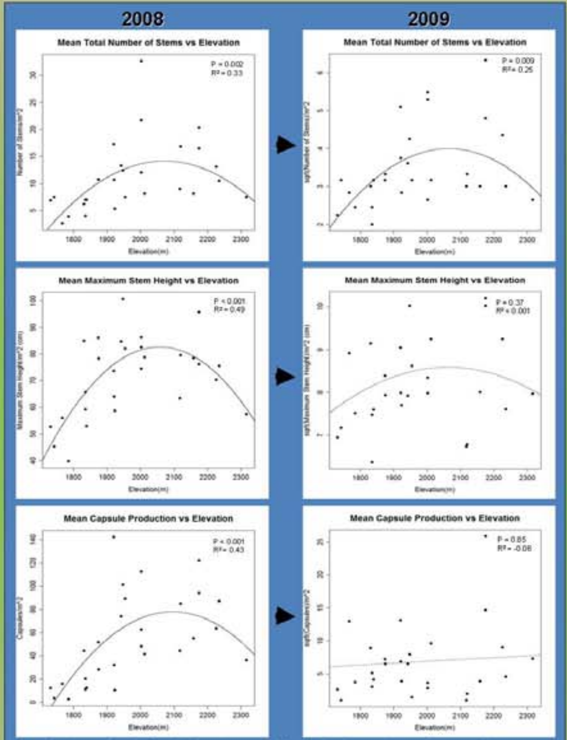
## Objective/Methods

**Question:** Is the demography of *L. dalmatica* affected by an elevation gradient within its current range in the GYE?

**Methods:**

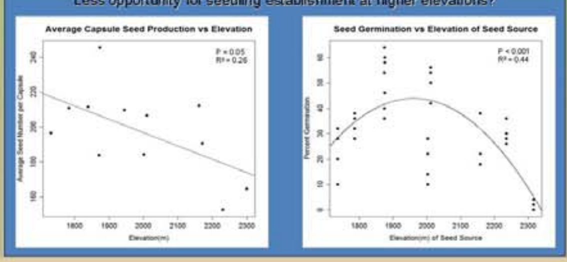
- Three replicate elevation gradients (combined range of 1,700 m to 2,900 m) located in Northern Range of Yellowstone National Park
- 6 monitoring sites per gradient
  - 2-3 patches per site, measured with multiple $m^2$ plots (total patches monitored = 27)
- *L. dalmatica* measurements:
  - Stem density per $m^2$
  - Seed capsule production per $m^2$
  - Maximum stem height per $m^2$
  - Seed production per capsule (45 capsules at each of 12 sites)
  - Seed germination/viability (100 seeds at each of 9 sites)
- Initial models fitted using simple linear regression with quadratic terms
- Future models will incorporate the following site specific environmental data:
  - Vegetative community composition
  - Overhead canopy cover
  - Temperature
  - Soil characteristics
  - Precipitation and soil moisture
  - Slope
  - Aspect

## Results



Quadratic models of *L.dalmatica* variables with elevation as the predictor variable.

Less opportunity for seedling establishment at higher elevations?




## Conclusions

- The growth and reproductive output of *L. dalmatica* is affected differentially along an elevation gradient.
- Trends in factors which are related to individual plant growth within a given year (stem height and capsule production) appear to be more variable than the trend in stem density, which is most likely tied to the general (long-term) site conditions.
- The differences in trends between 2008 and 2009 suggest that environmental conditions which vary from year to year, such as precipitation (2009 was a wetter year), may override general site conditions in terms of their effects on seasonal growth of individual plants.
- The declines in average number of seeds produced per capsule with elevation, and in initial germination rate under standard conditions with increasing seed source elevation, suggest that population growth via sexual reproduction may be more limited at higher elevations.
- The unimodal curves suggest current high and low range limits for *L. dalmatica* along the elevation gradients, and the patterns along the gradient suggest that these limits are due to changing environmental conditions. Therefore, further modeling of this species with more specific environmental predictors is justified.


Typical *L. dalmatica* habitat in the Northern Range of Yellowstone National Park.

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