Alpine tundra habitat loss in the Changbai Mountains, Northeast China

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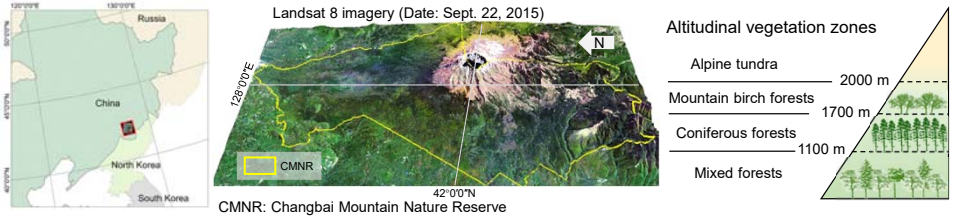
Background:
The alpine tundra located at the top of the Changbai volcano has been without human disturbance (e.g., grazing) for several hundred years. Dominant plant species include the evergreen shrub *Rhododendron aureum*, as well as deciduous dwarf shrubs like *Vaccinium uliginosum* and *Dryas octopetala* var. *asiatica*, sedge communities dominated by *Carex pseudo-longerostrata*. This alpine tundra has warmed significantly at an average rate of 0.028 °C /year from 1959 to 2017. As a consequence, there have been significant vegetation changes including ascending treeline, herb encroachment, and endemic shrub contraction, which lead to habitat loss of the alpine tundra.



CMNR: Changbai Mountain Nature Reserve

Figure 1. Location of the alpine tundra of the Changbai Mountains, Northeast China.

[1] **Ascending treeline** in response to climate warming

Materials and Methods: Field sampling, Dendroecological approach

Findings: Over the past 160 years, **the treeline increased by around 80 m**, a process that can be divided into three phases of different rates and drives. The first phase was mainly influenced by vegetation recovery after an eruption of the Tianchi volcano in 1702. The slowly upward shift in the second phase was consistent with the slowly increasing temperature. The last phase coincided with rapid warming since 1985, and shows with 33 m per 1°C, the most intense upward shift.

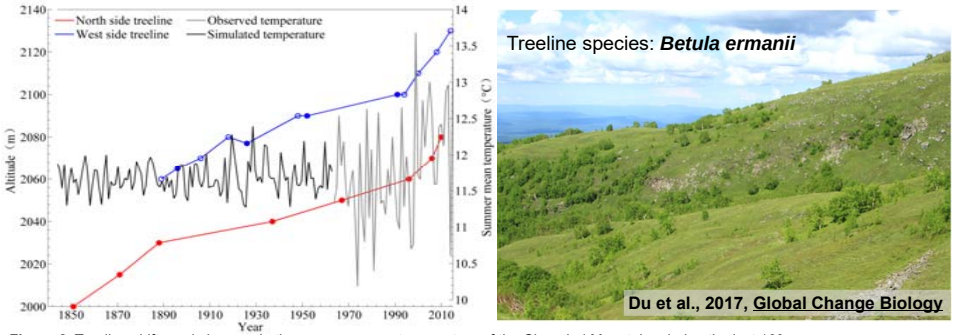


Figure 2. Treeline shifts and changes in the summer mean temperature of the Changbai Mountains during the last 160 years.

[2] **Herb encroachment** from low elevations

Materials and Methods: Field sampling, remote sensing, OTC and fertilization experiments

Findings: According to remote sensing observation, *D. angustifolia* patches gradually increased during the past three decades. Under warming (OTC) and fertilization experiments, *D. angustifolia* grew in response to added nutrients but did not grow well when temperature increased. Apart from climate warming, nutrient perturbation may be important in promoting herb encroachment into alpine tundra.

Figure 3. Encroaching herb patches in the alpine tundra landscape, Changbai Mountains.

[3] Upward range shift in a dominant shrub related to snow cover change

Materials and Methods:
Snow dataset: Multi-source satellite images including KeyHole-4B, Landsat 5/7/8 that covered the entire snowmelt period (1 April to 15 June) from 1965 to 2019.
Vegetation dataset: Landsat 5/7/8 that covered a time window in autumn (20 September to 10 October) from 1988 to 2019.

Target plant species:
Rhododendron aureum, the ONLY evergreen plant species in this study area, requires snow cover protection from extreme low temperatures to survive in alpine ecosystems.

Findings: Advances in snowmelt dates would lead to the upward range shift of *R. aureum* in a warming climate.

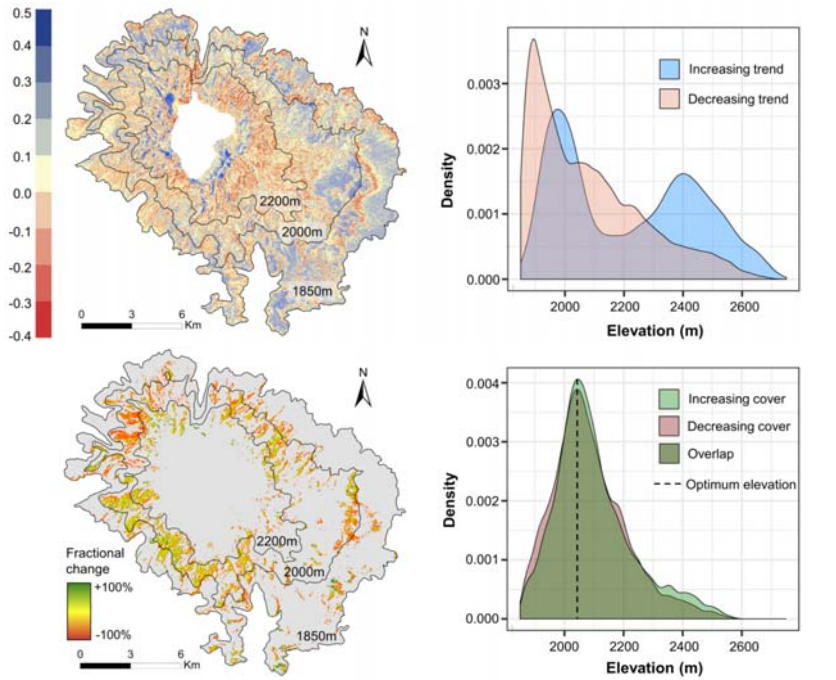


Figure 4. Decreasing snow cover (upper) and upward range shift of *Rhododendron aureum* (lower) in the Changbai Mountains, Northeast China.

Zong et al., 2022, Remote Sensing of Environment

Conclusions and significances:

- The spatial distribution and age structure of trees beyond the current treeline confirm the latest, warming-induced upward shift. Our results suggest that the alpine treeline will continue to rise, and that the alpine tundra may disappear if temperatures will increase further.
- Herb encroachment could deeply change the biodiversity of tundra vegetation and may eventually result in the replacement of native biota, especially with nitrogen addition. Our research indicated that nutrient perturbation may be more important than temperature perturbation in promoting herb encroachment upon the nutrient- and species-poor alpine tundra ecosystems.
- Spring snow cover change affected distribution changes of alpine endemic shrubs. Our study highlights that long-term changes in snow cover due to climate change have already had marked impacts on plant species distributions in alpine ecosystems.