

Impacts of climate change on plant and herbivore and their interaction

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Abstract: Changes in climate may affect plant-herbivore interactions and, in turn, ecosystem processes. However, there is a paucity of research on the effects of climate change on plant-herbivore relationships. Given the different environments in which above- and below-ground organisms live, their responses to climate change are likely to be different. However, there is a paucity of research on biological and ecological responses under current and future climate conditions. Although some studies have focused on the effects that climate change will have on interactions between herbivores and other organisms, there is no evidence for this. Interactions between plants and herbivores are of interest due to the high herbivory of animals in lowland tropical rainforests and the high defence capacity of plants. In contrast, most herbivores in the tropics are predominantly young and leafy, and therefore require constant target searching. Based on the strong link between ecology and evolution, plant-herbivore interactions in the tropics may be more susceptible to disruption by climate change.

1. Introduction

Climate change has a great impact on ecosystem, plants and herbivore. Plants and animals can't live without food, water, habitat, sunlight, etc. If the changes in climate are mild, animals and plants may adapt and thrive. However, the current climate change has seriously affected the survival of plants and animals. Researchers have shown that a warming climate can affect entire ecosystems. With the warming of the climate, the number of some plants and animals has been sharply reduced or even endangered. The interactions between plants and herbivores have influenced the ecology of nature and the evolutionary history of the species with which they are associated. During the late Silurian to early Devonian, some animals began to feed on plant tissue. As a result, plants evolved mechanical and chemical defences to defend themselves against herbivores from that time onwards. Co-evolution between plants and herbivores led to a greater diversity of species, forms, and functional traits.

Although both plants and herbivores have evolved intensely and over time, these evolutions have occurred in the context of possible changes in the abiotic environment. Changes in the abiotic environment can alter ecologically significant interactions and therefore play a key role in the expression of traits in both plants and herbivores. For example, during the Paleocene-Eocene thermal peak, fossil plants show that they were more readily found by herbivores during that period relative to cooler periods under conditions of significantly increased carbon dioxide concentration. Currently, as atmospheric emissions of greenhouse gases increase, global temperatures rise and nitrogen deposition increases, the natural world faces a shift towards new assemblage forms of species and populations. In the face of climate change, interactions between plants and herbivores may shift, which could alter ecological as well as evolutionary histories. Insects have shorter generation turnover, greater reproduction and greater mobility, so insects adapt more easily to climate change than plants, which may lead to less change in biological assemblages [1].

Based on the above analysis, plant populations may become food for different herbivores in a warming climate. Plant-animal interactions caused by changes in insects as a result of global warming

have attracted the interest of researchers. Changes in climate can affect the physiological characteristics, morphology and developmental status of plants. Studies have shown that as carbon dioxide concentrations increase, photosynthesis in plants increases significantly, plant biomass is significantly higher and water use is also significantly higher. In addition, an increase in carbon dioxide increases the proportion of carbon in leaf tissue in plants, which may reduce the nutritional value of the plant, however, this increases plant productivity and biomass. Further, ozone can enter the leaves through the plant's stomata, which can reduce photosynthesis, inhibit plant growth and reduce biomass. The secondary metabolites of the plant protect the plant from excessive damage by herbivores, however, both primary and secondary metabolites of the plant are affected under conditions of high concentrations of carbon dioxide. When plants exposed to aphid, they will reduce size because the plants' grown elevated CO₂.

Phylogenetically corrected meta-analyses suggest that increased temperatures, increased atmospheric CO₂ concentrations, drought and altered nutrient conditions all directly or indirectly increase the demand for food by herbivores, which in turn leads to a decline in plants. Studies have shown that an increase in CO₂ concentrations in the environment in which herbivores live can slow their growth and development. However, increased temperatures can enhance the growth and development of herbivores. As plants and animals evolve and abiotic conditions change, their interactions change to varying degrees. By studying the effects of abiotic factors on plant and herbivore traits, we can assess the impact of climate change on plant-animal interactions. Palaeontology has documented herbivore populations in response to prolonged global warming, showing a gradual increase in herbivore abundance with increasing temperature. Furthermore, according to phylogenetically corrected meta-analyses, herbivore diet changes in response to changes in CO₂ concentration, drought stress, nutrient content and composition. Further, an increase in CO₂ concentration hinders the growth and development of herbivores. At the same time, temperature also affects the development of herbivores to a greater or lesser extent. For plants with a one-year growth cycle, the impact is even greater. Currently, human actions such as car emissions and the burning of fossil fuels in factories produce large amounts of CO₂, resulting in changes in temperature, precipitation and nitrogen deposition. However, few studies have explored how these shifts interact with each other [1]. The combination of multiple climatic factors allows prediction of the effects of climate change on plant-herbivore interactions, which is of great importance for research in this area. Therefore, changes in the phenology and distribution of insects as well as plants need to be considered in order to explore the ecological mismatch patterns between them. In addition, it is necessary to consider how these changes contribute to mutual adaptation and co-evolution between plants and herbivores. These interactions play an important role in the changes in Arctic ecosystems. While herbivores can alter the evolution of plants and ecosystems, however, the direction of these and the extent to which they evolve is largely determined by the combination of environments. For Arctic plants and herbivores, the interactions between them are seasonal, with these areas having a short period of time available for plant growth, cooler temperatures, and producing less plant mass. As a result, tundra plants in the Arctic are less able to respond to herbivores. This results in the need for herbivores to constantly adapt to changes in the tundra plants. There are important implications for the study of Arctic herbivores in the face of plant and environmental change.

This study focuses on the relationships between plants and herbivores in the Arctic and explores ways of understanding these relationships. The main focus is on invertebrate herbivores and managed grazing systems. It is of interest to explore environmental change through the study of herbivores because of their more pronounced responses to environmental change. Further exploration of the subject will allow scientists to predict environmental trends in the Arctic.

2. Impacts of climate change on plant and herbivore

2.1 The importance of plant and herbivore in ecosystem

Herbivores are important in an ecosystem for many reasons. First, they are a food source for carnivores. Second, their fecal wastes fertilize and bring back nutrients to the soil, which are needed by plants. Third, they check the population of plants, preventing from dominating an ecosystem. When a population of specific organisms becomes too large, it results in an imbalance. It reduces the diversity of living things in the ecosystem.

2.2 Impacts on plant

Climate change cannot be considered only in terms of warming, but also in terms of the impact of climate change on plants, as it can affect their life cycle. The rapid growth and distribution of plants is influenced by the minimum, maximum, and average temperatures of the area in which it grows. However, the timing of warming and cooling in each region also changes gradually over the course of each year. For example, for high latitudes, warm weather starts later in the spring and stays warmer for longer in the autumn. In the Arctic, temperatures rise more rapidly and are milder in the summer, resulting in changes in the growth of vegetation in the region. However, not all plants are affected by the rise in temperature and are slow to develop. One study shows that many North American plant species are gradually moving to warmer areas, even downhill. Researchers at the University of Washington selected 300 species of plants in western North America to study a variety of aspects. The study concluded that 60 of these species are moving to lower elevations as the global climate warms. This is partly due to the impact of precipitation on the availability of water to plants [2].

2.3 Impacts on herbivore

For climate change projections, the proportion of herbivores is a key influencing factor. An increase in carbon dioxide in plants will reduce the nitrogen content of their leaves, so each herbivore will need to eat more leaves if it wants to replenish the same amount of energy. For arid areas, an increase in CO₂ can lead to a significant increase in the number of herbivores. Until 2.6 million years ago, the Arctic tundra had few herbivore species due to human extinction, which severely affected the tundra ecosystem. In addition, this is strongly linked to the constant changes in climate. Some researchers claim that the current presence of herbivores significantly affects the composition and function of tundra ecosystems. At the same time, they claim that climate warming may affect invasive tundra species, yet the presence of herbivores may slow the impact on the ecosystem. Current researchers are focusing on studying the role of herbivores in facilitating the transformation of different vegetation. One of these focuses on the transition between tundra and forest. Another is to focus on the transformation between grassland, moss, shrubs and tundra. It was concluded that herbivores can facilitate the transition between them to some extent and that the more diverse herbivores show a greater capacity for this transition. Although many of the larger herbivores, especially the super-sized ones, have already become naturally extinct, it is possible that the reintroduction of large herbivores in many Arctic regions could reduce some of the effects of climate change on plants [3].

3. Impacts of climate change on plant/herbivore interaction

Plants and animals evolved together. This process of interdependent evolution of two or more species is called coevolution. Some relationships are beneficial to both parties, while others have a clear benefit for one at the other's expense, or even death. One important plant/animal relationship is plant/herbivore interaction, where an animal consumes a plant or portions of the plant.

This study has chosen some typical examples of plant/herbivore interaction and discussed the impacts of climate change.

3.1 Factors

Climate change affects plant/herbivore interaction in many aspects, three main factors were concluded:

3.1.1 Rising temperatures

In Jill T. Anderson's study, a moderate rise in temperature can increase plant productivity and production of secondary metabolites. Severe drought could accompany heatwaves associated with climate change and have adverse effects on plant productivity.

Claudio de Sassi and Jason M. Tylianakis' s study showed similar result: warming temperature plant relative biomass did not increase significantly, plant biomass might be reduced, or their increase has been limited through this top-down effect.

According to Claudio de Sassi and Jason M. Tylianakis' s research, drought negatively affects plant productivity and alters chemical plant defenses as well as nutritional quality, digestibility, and palatability in general. In agricultural systems, drought severely limits the ability of plants to acquire soil nutrients. Thus, it is important to consider fertilization at a regional level and in combination with other climate change factors.

3.1.2 Elevated CO₂

Increased atmospheric CO₂ concentrations alter the carbon and nitrogen economy within the plant, decreasing the N concentrations in plant tissue, diminishing the nutritional quality of plant tissues by reducing concentrations of proteins and certain amino acids in leaves. Dash C. et al. and Hamann E. et al.'s paper briefly discussed this phenomenon.

Dash C. et al. showed that when the concentration of carbon dioxide exposed to plants increases, photosynthesis increases significantly, water use efficiency increases, and plant biomass increases. Elevated CO₂ increases the C: N ratio in plant leaf tissue, thereby increasing their growth rate and reducing their nutritional value. These changes will result in an increase in plant productivity and biomass. In addition, this elevation also alters the production of primary and secondary plant metabolites, which play a very important role in preventing plant encroachment by herbivores. When plants exposed to aphid, they will reduce size because the plant's grown elevated CO₂.

In Hamann E. et al. 's case, increased atmospheric CO₂ concentrations alter the carbon and nitrogen economy within the plant, decreasing the N concentrations in plant tissue, diminishing the nutritional quality of plant tissues by reducing concentrations of proteins and certain amino acids in leaves.

3.2 impacts in different regions

3.2.1 Alpine

The biomass of the plants from the upper canopy decreased more than the understory of the vegetation, altering the functional dominance in the vertical structure of the vegetation. Colonisation by low-land plants might be facilitated through the less competitive environment. Biomass of dominant plant reduced, coexistence favored.

In de Sassi C., Tylianakis J.M. [2012], a trend of disproportionate increase between plant and herbivore biomass was found. Herbivore biomass retained a positive effect of temperature, it increased significantly (doubled on average). Herbivore biomass retained a positive effect of temperature, it increased significantly (doubled on average, Fig. 1). In contrast, plant relative biomass did not increase significantly compared to the herbivores at higher temperatures. The study proposes that the elevated temperature could have led to increased herbivory of the herbivores, where Plant biomass might be reduced or their increase has been limited through this top-down effect.

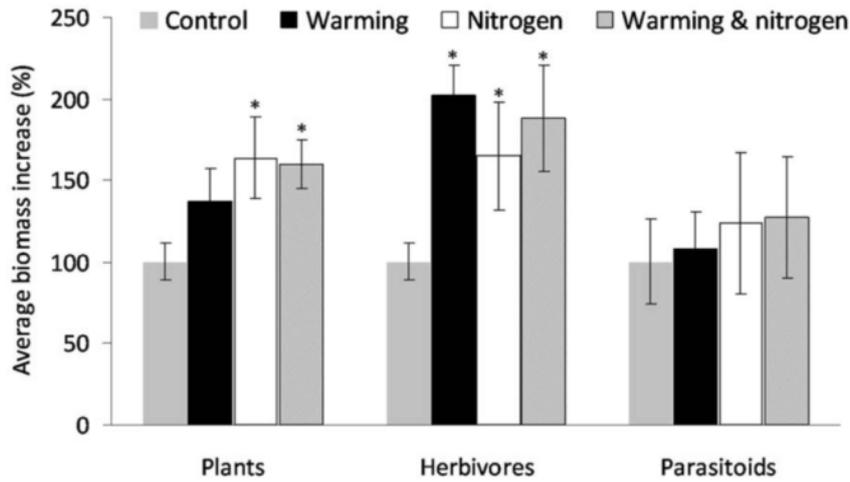


Fig. 1. The effect of the global change drivers (warming, nitrogen and their combination) on the percentage increase in biomass relative to the control treatment for plants, herbivores, and parasitoids

Hamman E. et al. [2020] found that higher CO₂ concentrations diminish the nutritional quality of plant tissues by reducing concentrations of proteins and certain amino acids in leaves, reduce the conversion efficiency of ingested food for herbivore insects. Only leaf chewers significantly increased their food uptake in elevated CO₂ conditions. The increased herbivory could impose strong selection on plant populations for constitutive and inducible defenses. The Accelerated metabolic rates of ectotherm herbivores under elevated temperature could lead to higher consumption, growth, and faster development, which would increase population growth rate and reduce generation time. The Warming temperatures could favor thermal plasticity which could alter phenology and growth. Furthermore, warmer winters and earlier springs associated with climate change could increase herbivore overwinter survival. The rapid changes in herbivore performance and life-history traits could render plant populations more vulnerable to herbivores (Fig. 2).

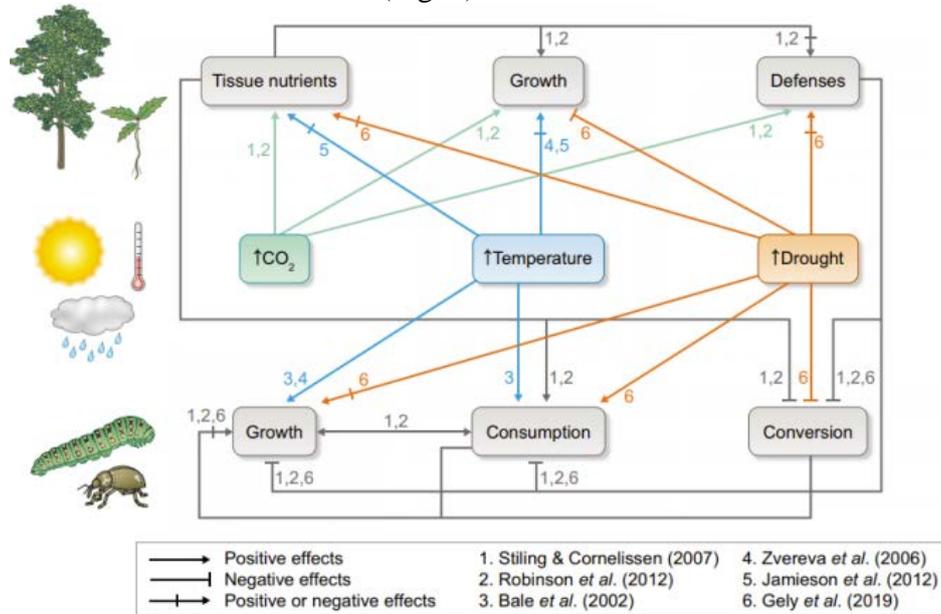


Fig. 2. Effect of single climate change factors on plant growth, tissue nutrients status and defenses and insect growth, consumption and food conversion efficiency

It had been found that Climate change indirectly caused alpine communities to be colonized by low-land herbivores including the orthopterans, causing novel trophic interactions. Descombes, P. et al., (2020) found Higher herbivore pressure reduced the frequency of dominant plant species with tougher leaves and distinct chemistry matching the trophic preferences of the herbivores in their habitat

of origin (Figure 1). The Biomass of the plants from the upper canopy decreased more than the understory of the vegetation, altering the functional dominance in the vertical structure of the vegetation. The decrease in estimated plant biomass for a taxon of plant similar to the preference of the herbivores from their low-land origin leads to enhanced light availability at the ground level, plants that are low in stature and contains tannin in their leaves gained a net increase in species richness (Fig. 3). It had been proposed that the colonisation by low-land plants might be facilitated through the less competitive environment. Overall, the biomass of the dominant plant reduced, coexistence favored (Fig. 4).

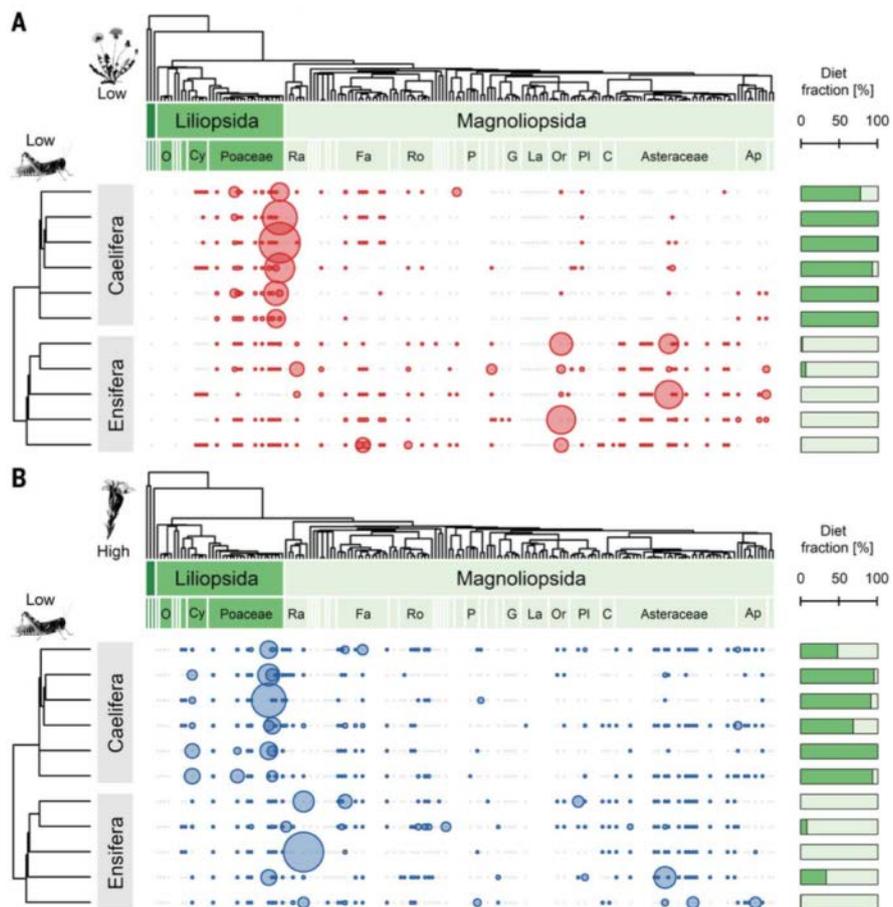


Fig. 3. Diet preferences of the herbivores at low-land origin and alpine community. Shown are feeding patterns of orthopteran species from the lower-elevation collection site on lowland plants occurring at the collection site (A) and alpine plant species occurring at the mid-elevation experimental site (B).

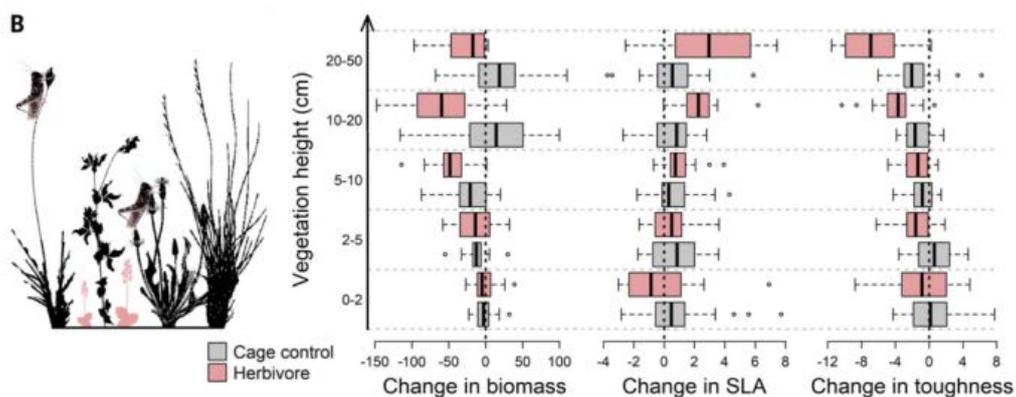


Fig. 4. Changes in estimated plant biomass, SLA (mm^2/mg), and leaf toughness ($\text{GN}/\text{m}^2/\text{m}$) along with the vegetation height under herbivore incursion treatment and in cage controls.

Studies have shown that the rising temperature causing treeline to rise uphill. Illerbrun K., Roland J. [2011] showed that altered herbivory on lance-leaved stonecrop (*Sedum lanceolatum*) by Rocky Mountain apollo butterfly (*Parnassius smintheus*) larvae from the treeline to the meadow apex caused by treeline rise. The study site at Jumpingpound Ridge has a declined meadow area of more than 75%, which has been caused by treeline rise. *P. smintheus* tends to rely on foraging *S. lanceolatum* which are grown away from the tree line. A further treelike rise would lead to a greater fitness cost for *P. smintheus* larvae to forage.

3.2.2 Tropical Forest

In Coley, P. D. (1998), the canopy tree species in tropical forest experiences slightly higher growth rates under elevated atmospheric CO₂ levels. At the understory level, this effect is unclear as they might be limited by low light availability. Foliar nitrogen normally decreases by 10-30%, resulting in nitrogen dilution, leading to the mature leaves becoming less nutritious for herbivores. In response to the diluted nitrogen content, the herbivory of the insect herbivores increases, possibly by approximately 40%.

El niño which is related to climate change has lengthened the drought period. Coley, P. D. (1998) shows that drought affects adult trees less severely than understory shrubs. The water stress caused by drought reduces photosynthesis and growth, as well as leading to premature leaf abscission. Plants also use drought as a chance for synchronising the population. The mortality rate is elevated. Lengthened drought period has also led to increased herbivory rates for some insect herbivores up to 4-10 times. This results in more leaf damage for plants. For herbivore species with flexible growth patterns, outbreaks after drought could become common.

In addition, Coley, P. D. (1998) also found tighter coupling of herbivore live circle with plants with plant leafing may cause tropical interaction more susceptible to climate change. Most herbivores only eating one small subset of plants species.

3.2.3 High-Arctic

Plant-herbivore interactions in arctic environments occur under particular conditions characterized by marked seasonality, short growing seasons, low temperatures, and low primary productivity. Berg, T. B. et al., (2008) utilised long term data on trophic interactions between arctic plants, arctic willow *Salix arctica* and mountain avens *Dryas octopetala*; three arctic herbivores the moth *Sympistis zetterstedtii*, the collared lemming *Dicrostonyx groenlandicus* and the musk ox *Ovibos moschatus*. Climate change affects the timing and duration of the snow coverage. Lemmings seek areas with thick snow-cover provide protection from the cold and some predators. Therefore, lemmings may be affected directly by both the timing of onset and the duration of winter snow-cover. Muskoxen significantly reduced the productivity of arctic willow, under a deep snow-layer scenario, climate and the previous year's density of musk oxen had a negative effect on the present year's production of arctic willow. The previous year's primary production of arctic willow, in turn, has significantly affected the present year's density of musk oxen positively. Climatic factors affect the primary production of plants indirectly, which influenced the spatial distribution of herbivores. Additionally, snow distribution directly affected the distribution of herbivores, affecting the plant community by selective feeding and locally reducing the standing biomass of forage plants.

The annual phenology of flowering of the plants in the valley Zackenbergdalen varies widely between years, dependent largely on the date of snowmelt, the flower production shows large inter-annual variation, indicating that climate directly affects not only the timing of and investment in reproduction but also the development of plant tissue.

4. Conclusion

This paper highlights the importance of the plants and herbivores' interaction when making predictions on the effects of climate change on plant-mediated interspecific interactions. Plant-herbivore interactions are important for understanding community dynamics and ecosystem function

given that they are the critical link between primary production and food webs. Plant-herbivore studies are also the backbone of multiple fields within ecology and evolution, including co-evolution chemical ecology, nutritional ecology, and ecological stoichiometry. The topic crosses ecosystem boundaries, huge ranges of organismal size and vast productivity gradients resulting in broadly applicable ecological theories.

Across different communities, trends of responses to climate change have similarities and unique traits. The most general trend could be concluded as the warming temperature has caused increased herbivory of herbivores, resulting in top-down pressure from the herbivores to the plants, limiting the latter's biomass. Under warming temperatures, the metabolic rate of the ectotherms such as insects increases.

As mentioned above, the alpine community shows its unique trend, the colonisation of communities from lower to higher altitudes. However, it is shown in different circumstances. When the temperature rises, the insect herbivores first migrate further up the altitude, limiting the biomass of the dominant plant, resulting in a less competitive environment for plants from lower altitudes to move in.

The arctic community shows its unique trend. It could be concluded that snow distribution affecting herbivore distribution and primary plant production. The plant community brought top-down pressure, including reducing the biomass of local plant communities where the herbivores arrived. Therefore, through this process, the snow distribution indirectly affects the plant primary production by causing the herbivores to reduced plant productivity.

The tropical forest community also shows unique trends. Both tropic and alpine community has forests. Within the three communities we looked at, the effects of lengthened drought, which increased herbivory of herbivores and potentially led to outbreaks after drought, are also limited to the tropical forest.

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