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Forest vegetation responses to climate and environmental change: A case study from Changbai Mountain, NE China

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ABSTRACT

The distribution of plant species has always been altered by changing climatic conditions. Nonetheless, the potential for species' range shift responses has recently become severely limited, as exceptionally fast temperature changes coincide with a high degree of anthropogenic habitat fragmentation. This study provides rare insights into the effects current temperature increases have on pristine temperate forest ecosystems, using the forests of Changbai Mountain, NE China, as a case study. On the northern slopes of the mountain at elevations between 750 and 2100 m, the composition of trees, shrubs and herbaceous species was recorded on 60 plots in 1963 and 2006/07. Multiple linear regression (MLR) and canonical correspondence analysis (CCA) were used to establish the response of plant diversity and plant distribution patterns to environmental conditions. Climatic factors proved important in explaining the spatio-temporal trends within the vegetation. The composition of dominant trees remained mostly unchanged over the last 43 years, reflecting a very slow response of the forest canopy to environmental change. The composition of young trees, shrubs and herb species showed varied changes in the different forest types. A homogeneous species composition in the cohort of regenerating trees indicates an increased future uniformity in the mixed broadleaved and coniferous forest. The understory vegetation of high elevation birch forests was invaded by floristic elements of the lower-elevation coniferous forests. Both these trends pose potential threats to forests plant diversity. Future research investigating climate change responses in forest canopy composition needs to be based on even longer timescales, while investigations in the near future need to pay particular attention to the changes in the distribution of rare and threatened herbaceous species.

1. Introduction

Changes in climatic conditions and associated habitat patterns have always affected life on our planet (Kirilenko and Sedjo, 2007) and can even be seen as a key driver of evolution (Parmesan, 2006). During prehistoric times, plants could partly adjust to natural variations in temperature and precipitation by latitudinal and altitudinal shifts in their distribution ranges (Grayson, 2005; Tipping et al., 2008; Zenner and Berger, 2008). It was only with the onset of anthropogenic activities and the resulting strong increase in the fragmentation of natural habitats that the ability of plant species to adjust to changes in climatic conditions via shifts in their distribution ranges became severely limited (Liira et al., 2007; Malhi et al., 2008). Initially, fragmentation and isolation of habitats might protect their species from being out-competed by species better adapted to increases in temperature and precipitation changes (Kissling et al., 2008). Nonetheless, it can be expected that the fitness of many species will eventually decrease, leading to changes in the composition of the vegetation and to a decrease in local species diversity (Chust et al., 2006).

Changes in the vegetation can be expected to be particularly pronounced in forests, which represent not only the most phytodiverse terrestrial ecosystems (Kirilenko and Sedjo, 2007), but are also affected by drastic changes in their microclimatic conditions especially in small forest fragments (Rosenzweig, 1992). The effective long-term conservation of forest ecosystems therefore requires the protection of at least some large pristine forested tracts. These areas will not only allow the preservation of their unique flora and fauna, but can also form an important study base to gain insights into the inherent shifts in plant species compositions in reaction to climate change. These insights are crucial for the conservation and successful management of smaller forest patches, for example via the enrichment with rare species for which they provide suitable habitat conditions as a result of changed temperature and precipitation regimes (Lozano et al., 2007; Zenner and Berger, 2008). A thorough understanding of the reaction of forest

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ecosystems to climate change is also of great importance in reforestation projects, for example in the selection of species suitably adapted to future climatic conditions (Harger, 1993).

Current anthropogenic changes in global temperatures are very rapid in comparison to most prehistoric temperature shifts (McCarty, 2001). It therefore remains unclear if and how well the vegetation can cope with these dramatic habitat alterations, even in areas where opportunities for range shifts are theoretically available. In comparison to plant formations dominated by herbaceous vegetation, forests are of particular concern due to the longevity of trees and the associated long timespan required for adaptations in the species composition of the forest canopy to take effect. This further underlies the importance of in-depth scientific research to assess the changes of forest ecosystems as a result of climate change.

A growing number of studies focus on long-term changes in the vegetation (Anderson and Inouye, 2001; Pauli et al., 2007) and associated changes in the carbon balance (Phillips et al., 1998; Clark, 2002) in reaction to climate change. Most of these studies nonetheless focus on the depleted flora of Europe or in the America, while long-term studies of vegetation change from the phytodiverse Asian region remain very scarce. The Changbai Nature Reserve (CNR) in NE China on the border near North Korea provides a rare opportunity to conduct such an investigation. The reserve has been established in 1960 to protect China's last remaining large areas of pristine temperate forests, including mixed broadleaved and Korean pine forest (Yang and Xu, 2003; Sang and Bai, 2009). The vegetation of the reserve was studied in detail in the early 1960s (Chen, 1963; Chen et al., 1964). As summer temperatures in Northeast China have increased by about 0.15 °C per decade over the last 50 years (Li et al., 2005), it is not surprising that changes were observed in plant diversity since this first survey (Bai et al., 2008; Wang et al., 2010). Using data collected during a re-surveying campaign in 2006 and 2007 of the plots and forest types sampled in the 1960s, we now aim to establish the nature and strength of links between environmental factors, including both climatic and edaphic parameters, and the spatial and temporal changes in the forest vegetation. In our research, we distinguish between the different forest types occurring on the northern slopes of Changbai Mountain and the different vegetation strata occurring in these forests.

2. Material and methods

2.1. Study area

The Changbai Nature Reserve is located in the Jilin Province, NE China. The climatic conditions within the CNR are influenced by monsoon rains. The vegetation in the reserve therefore experiences dry, windy springs, short rainy summers, cool autumns with a high frequency of fog, and long, cold winters. While the temperature decreases, the precipitation generally increases with increasing elevation (Chi et al., 1981).

Following this climatic gradient, the CNR is characterized by a clear altitudinal zonation of the vegetation (Chen et al., 1964; Zhao et al., 2004; Wang et al., 2010). Areas below 1100 m are covered in mixed coniferous and broad-leaved forests (MCBF) associated with a large variety of co-dominant tree species, including *Pinus koraiensis* Sieb. and Zucc. 1842, *Acer mono* Maxim. 1857, *Tilia amurensis* Rupr. 1869, *Ulmus davidiana* Planch. var. *japonica* (Rehd.) Nakai 1932 and *Quercus mongolia* Fish. ex Ledeb. 1850. Between 1100–1500 m, mixed coniferous forest (MCF) dominated by *P. koraiensis*, *Picea jezoensis* Carr. var. *microsperma* (Lindl.) Cheng and Fu 1861, *Abies nephrolepis* (Trautv.) Maxim. 1866 and *Larix olgensis* Henry 1915 forms the main forest type. Sub-alpine coniferous forests (SCF) cover the slopes between 1500 and 1800 m. Dominant tree species in these forests are again *P. jezoensis*, *L. olgensis* and *A. nephrolepis*. The highest forests growing at altitudes between 1800 and 2100 m are birch forests (BF) dominated by *Betula ermanii* Cham. 1831. Elevations above 2100 m are covered in tundra vegetation composed of *Rhododendron aureum* Georgi 1772, *Rh. redowskianum* Maxim. 1859, *Vaccinium uliginosum* L. 1839 and other low shrub and grass species. This study focuses on changes in the forest vegetation, covering the entire range of forest communities between 800 and 2100 m on the Northern slopes of Changbai Mountain. Individual survey plots are located between 127°55′E and 128°08′E and 42° 03′ N and 42° 23′ N (Fig. 1).

2.2. Vegetation surveys

Detailed vegetation surveys were conducted in plots representing the four main forest types occurring in the study area. The

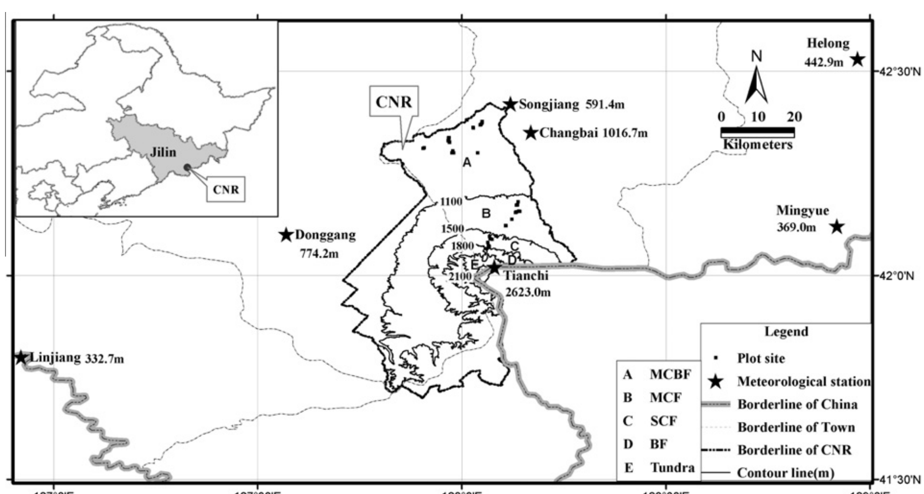

Fig. 1. Distribution of vegetation zones and sample plots on the northern slopes of the Changbai Nature Reserve (MCBF: mixed coniferous and broad-leaved forests; MCF: mixed coniferous forest; SCF: sub-alpine coniferous forest; BF: birch forests; D: alpine tundra). (A) mixed coniferous and broad-leaved forest zone (MCBF) (below 1100 m a.s.l.), dominated by *Pinus koraiensis*, *Acer mono*, *Tilia amurensis*, *Ulmus davidiana var. japonica*, *Quercus Mongolia*, etc.; (B) mixed coniferous forest zone (MCF) (1100–1500 m a.s.l.), dominated by *P. koraiensis*, *Picea jezoensis var. komarovii*, *Abies nephrolepis*, *Larix olgensis var. changpaiensis* etc.; (C) sub-alpine coniferous forest zone (SCF) (1500–1800 m a.s.l.), dominated by *Picea jezoensis* var. komarovii, *Larix olgensis* var. *changpaiensis*, *Abies nephrolepis*; (D) birch forest zone (BF) (1800–2100 m a.s.l.), dominated by *Betula ermanii*; and (E) tundra zone (upon 2100 m a.s.l.), dominated by *Rhododendron aureum*, *Rh. redowskianum*, *Vaccinium uliginosum* var. *alpinum* etc.