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The effect of forest disturbance on landscape temperature

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ABSTRACT

Since the 1990s, the territory of the Šumava National Park (Czech Republic) has faced significant changes in land cover, especially deforestation, in conjunction with several bark beetle disturbances and hurricane Kyrill in 2007. The aim of the study is to review the hydrological and climatic function of the forest and deforestation impacts on the landscape temperature. As a case study, surface temperature changes of the selected area of Šumava National Park from the satellite Landsat thermal data is presented from 1991 to 2016. At the sites with decayed forest, the surface temperature increased by 2–4 °C. Images from ground temperature measurements illustrate extreme temperature differences (~35 °C) at locations where dead wood has not been removed; in the live forest, they are around 5 °C. Further, we show the increase in air temperature is associated with the decay of forest stands, including snow melting. The duration of the permanent snow cover on the mountaintops with the growing forest in the last four years is, on average, 11 days longer than the areas with decayed forest. The results show that the increase in surface temperature in the large area causes changes in the local climate and hydrological regime. These changes may have a negative impact on the surrounding ecosystems, including the Šumava wetlands and peat bogs belonging to the Ramsar sites.

1. Introduction

1.1. Opinions on the role of forests in water balance/hydrology and climate

The debate on the role of forests in the hydrological cycle can be traced back in history – Antiquity, Middle Age and up to the present. Man tried to understand the impact of forests on the water cycle and was aware of the serious consequences deforestation had on hydrology, soil, climate, precipitation, and temperature. The role of forest stands and the consequences of their damage were based on long-term observations and personal experience; scientific measurements and the effort to describe the whole system in scientific terms appear in the 19th century. Adult forests dampen the extremes of climate; this is the experience of both historical civilizations and generations of landscape managers, which was reflected in the Forest Law from the 18th century in the Austrian Monarchy. Over a long period of time a series of scientific papers and books were published on damping of temperature extremes (Geiger, 1957; Geiger et al., 2003, 2009). Forest practitioners wrote comprehensive books based on long- term experiences explaining the irreplaceable hydrological role of forests (Marsh, 1864; Úlehla, 1947).

Andréassian (2004) gives a historical evolution of ideas on the role of forests in hydrology and shows results of 137 paired watershed studies: deforestation was always immediately followed by a period of water yield increase and the subsequent period of recovery (forest regrowth) may or may not be characterized by a decrease in water yield.

WeForest (2015) and Ellison et al. (2017), in a thorough review, state the following five forest processes as more important than previously thought. Management to support them can result in short and long-term benefits for water availability and climate:

1. Forests promote precipitation.
2. Trees and forests are natural cooling systems.
3. Forests generate air and moisture flows.
4. Trees and forests can improve groundwater recharge.
5. Forests can moderate flooding.

The authors bring evidence both from ecophysiological studies and from evaluation of how large forest complexes function. They emphasize the direct role of forests in the distribution of solar energy, cooling, water cycle, and local climate.

The IPCC (Intergovernmental Panel on Climate Change) and mainstream science focus on the role of forests and wetlands in global climate change in terms of the greenhouse effect: forests affect climate by serving as a sink/source for carbon dioxide and other greenhouse gases (GHGs). Forests affect the climate positively through carbon dioxide

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sequestration. On the other hand, a forest is dark (low albedo) and absorbs solar radiation, which contributes to planet warming. According to Bala et al. (2007), burning of boreal forest would contribute to planet cooling because the warming caused by the release of carbon dioxide is lower than the cooling effect of increased albedo (the reflection of solar radiation) of burned forest. This thesis considers the forest as a passive subject of global warming driven by an increasing concentration of GHGs. According to the IPCC, the radiative forcing has increased since 1750 by 1–3 $W \cdot m^{-2}$ and resulted in higher evapotranspiration and water losses from the landscape by evaporation. The IPCC (2013, p. 666) claims that land cover does not affect the amount of water in the atmosphere; it is global warming which accelerates evaporation. Therefore, the only way to mitigate global warming and climate change is to reduce GHG production. Adaptation is based on the cultivation of species that tolerate lack of water and higher temperatures.

1.2. Forests attract water from oceans several thousand km deep in continents

Evapotranspiration from forests plays an extensive role in the transport of moisture from oceans to continents. It is evident that annual precipitation is high in continents with large and continuous tracts of forest that extend from the coast to the continental interior (West Africa, Amazonia). The biotic pump theory (Makarieva and Gorshkov, 2007, Makarieva et al., 2009) suggests the atmospheric circulation that brings rainfall to continental interiors is driven and maintained by large, continuous areas of forest beginning from coasts. The theory explains that through transpiration and condensation, forests actively create low-pressure regions that draw in moist air from the oceans, thereby generating prevailing winds capable of carrying moisture and sustaining rainfall far within continents.

The biotic pump concept explains why moist winds blow readily from oceans to well- forested land. This flow can decline and reverse when forest cover is absent or depleted. Deforestation reduces this pressure difference, weakening or removing the coast-to- interior moisture transport. Reliable rainfall in the continental interiors of Africa, South America, and elsewhere (EuroAsia) may thus be dependent on maintaining relatively intact and continuous forest cover from the coast.

The Šumava (Czech Republic) and Böhmerwald (Germany – Bavaria and partly Upper Austria) Mountains represent the largest forest complex in Central Europe on the boundary between Atlantic and continental climates. The Šumava National Park was declared in 1991 on 68,060 ha (ha), of which 55,000 ha are forested. An unmanaged regime for wilderness development was adopted and up until 2017 up to 17,000 ha of adult spruce forest declined or had to be cut due to bark beetle infestation, which represented roughly 6 million dead adult trees (note: as a large calamity is considered more than million m^3 of dry wood; one dead tree represents approx. 1 m^3 of wood) The expansion of the unmanaged zones continues to be promoted, with the aim of achieving a wilderness cover of 51% in the NP territory. Over the last several decades, a heated discussion has taken place among the media, Parliament, local communities, and among scientists on the effects of declining adult forests on hydrology and regional climate. The administration of the Šumava National Park, nature conservationists, and scientists advocate the thesis that hydrological function of a declined adult forest is compensated for by the ground vegetation. Foresters, most of the local people, communal politicians, and some scientists warn against the long-term slow process of drying linked with mountain deforestation. In order to assess effects of the decline of adult forest on regional climate following has been done:

- Assessment of long-term changes in surface temperature of the deforested areas, thermal data of Landsat satellites were evaluated for August of 1991, 1998, 2004, 2005, 2009, and 2016 and compared with Corine Land Cover data.
- For detailed evaluation of surface temperature differences between living and dead adult forest, ground thermal pictures were made in situ.
- The long-term trends of air temperature in the period 1988–2017 were evaluated for the meteorological station located in the mountain area where adult spruce forest declined and compared with the data of other meteorological stations located in undamaged areas.
- Time periods of snow cover duration in forested areas and in dead adult forest were evaluated.
- The data and results are discussed in terms of distribution of solar radiation (latent heat, sensible heat), evaporation and water cycle, and tree ecophysiology. Effects of deforested areas on valuable peat land mountain ecosystem are considered.

2. Specification of the area of interest, data and methods

The Šumava National Park (NP) was proclaimed in 1991 with an area of 680.6 km^2. The subjects of protection are forests, peat bogs and other wetlands, glacial relief, and cultural non-forested areas. Forest stands occupy 80% of the area, and the most valuable are mountain spruces reaching the forest boundary (1100–1300 m above sea level). In these plots, a non-intervention strategy was introduced in the 1990s, with the assumption of no bark beetle propagation. Ecological experts, unlike foresters, claim that these areas are resistant primeval forests, where the bark beetle is a natural part of the entomofauna and its overgrowth is impossible because of the presence of natural predators. However, bark beetle reproduction significantly increased from 2007 to 2011 after hurricane Kyrill. As a result of the non- intervention strategy, 17,000 ha of forest were lost in the Šumava NP (ÚHUL[1]) and 6500 ha of forest were lost in the neighbouring Bavarian NP, which is an estimated 8 million trees. Despite these events, the expansion of the non-intervention areas continues to be promoted, with the aim of achieving 51% wilderness cover in the NP territory.

The area of interest extends on the subset of Landsat satellite scene covering 544 km^2 (27.66 × 19.65 km), with the coordinates 49°05′53″ N, 13°19′34″ E and 48°55′34″ N, 13°42′34″ E. It is the transboundary area (Bavaria), however, only the Czech part was assessed (383 km^2).

From the Landsat data archive (https://earthexplorer.usgs.gov/), six free-clouds scenes (number 192-026) were selected from the following years:

Satellite Landsat 5: 7. 8. 1991, 10. 8. 1998, 10. 8. 2004, 29. 8. 2005, 24. 8. 2009
Landsat 8: 27. 8. 2016

The scanning time was 9:40 GMT (Landsat 5) and 9:57 GMT (Landsat 8).

Landsat satellites scan the electromagnetic radiation in the thermal portion of the spectrum in the channels:

Landsat 5-channel B6, wavelength 10.4–12.5 μm.
Landsat 8 – B10 channels (10.6–11.2 μm) and B11 (11.5–12.5 μm).

The spatial resolution of thermal data (that is, the size of the area capturing one pixel) for Landsat 5 is 120 m; while Landsat 8 is 100 m.

The data is suitable for analysis of larger territorial units. However, they capture vast territories of several hundred square kilometres at one point in time. The surface temperature is averaged for the smallest pixel from several surface types, in the case of very heterogeneous coverage. Using the intensity of the radiation that is recorded in the thermal channels, it is possible to calculate the surface temperature by means of

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