INTRODUCTION

Forest decline and mortality during the last decades has been documented on every continent (Allen et al., 2009). Stands mortality was reported in Europe, including Spain (Perellós et al., 2001), France (Breda et al., 2006), Switzerland, Italy, Belarus, Ukraine (Bigler et al., 2006; Dobbertin and Rigling, 2006; Kharuk et al., 2014).

In Canada Populus tremuloides mortality was observed across a million hectares (Hogg et al., 2008; Anderegg et al., 2012). In the southwestern part of USA, drought-induced mortality of Pinus edulis was documented for an area of over a million hectares (Van Mantgem et al., 2009).

In Russia decline and mortality of “dark needle conifers” (DNC: Pinus sibirica, Abies sibirica and Picea obovata, Picea abies, Picea ajanis, Abies nephrolepis) were reported from the western border to the Russian Far East (Man’ko et al., 1998; Pavlov et al., 2008; Chuprov, 2008; Zamolodchikov, 2011; Voronin, 2012; Kharuk et al., 2013). The potential causes of forest mortality considered were over mature stands, drought, root fungi and insect attacks and bacterial diseases.

The objective of this study was to analyze temporal and spatial patterns and causes of fir decline and mortality in the Eastern Sayan Mountains, Siberia. We hypothesize that mortality was triggered by drought. We seek to answer the following questions: 1) When did fir mortality began? 2) What was a temporal and spatial pattern of mortality? How did mortality relates to topographic features? 3) How mortality connected with climatic variables?

STUDY AREAS

The study areas were located within East Sayan Mountains (Abies sibirica).

METHODS

Methods included field studies of forest health, dendrochronology analysis, satellite data and GIS analysis, and analysis of radial increment (tree ring width) with climatic variables (temperature and precipitation, drought index, water vapor deficit).

RESULTS

Tree mortality was triggered by severe droughts

Abies sibirica TRW chronology of (1) “survivors” and (2) “decliners” cohorts. Confidence interval (p < 0.05) shown by gray background. Bars: a percentage of sampled dead trees that died in the given year. 3 – TRW chronology of regeneration.

Abies sibirica and Pinus sibirica: relationship with relief features

Abies sibirica: relationship with climate variables

Drought index trends and stands mortality in Russia

Location of forest stands mortality in Russia. Background: evergreen conifer map (Bartalev et al., 2011). Color scale: SPEI anomaly. Sites: 2 - DNC of Kuznetzky Alatau Mountains; 3, 4 - DNC stands in southern Siberia; 5 - fir and Siberian pine site in southern Baikal area.

GRACE data

Tree-ring width (TRW) dynamics of (1) dead fir stands, (2) alive fir stands, and (3) residual water mass (Wt). The year of Wr minimum (2007) coincides with a date of stands mortality. In general, there is negative correlation between TRW and water mass derived from GRACE gravimetric data.

Stands decline is observing within ecozones between DNC and broadleaf forest-steppe, within marginal parts of DNC area. Within area stands declining at the relief features with a maximal water stress risk. Geographically those areas coincided with a low SPEI values (a drought zones).

CONCLUSIONS

1. Siberian pine and fir decline and mortality is observing in Siberia since end of 20th – the begin of 21th century.

2. Tree decline was correlated with water vapor pressure deficit and drought index.

3. Maximal decline and mortality were observed at relief features with a higher water stress risk (southern exposition, steep slopes, convex terrain).

4. Tree mortality was triggered by water stress and extreme droughts in a synergy with bark beetles and fungi attacks.

5. Initially stands decline and mortality were observed at the margins of tree species area, e.g., within DNC – forest-steppe ecozones. Within inner part of Siberian pine and fir area decline and mortality were located at the relief features with a maximal water stress risk.

6. In future climate Siberian pine and fir within part of its area will be replaced by more drought-resistant species (i.e., Pinus silvestris, Larix sibirica).

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