Drought-triggered conifer stands decline and mortality in Siberia

V.I. Kharuk, S.T. Im, I.A. Petrov

V. N. Sukachev Institute of Forest, Krasnoyarsk, Russia, (kharuk@ksc.krasn.ru)

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 (Pen˜uelas 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).

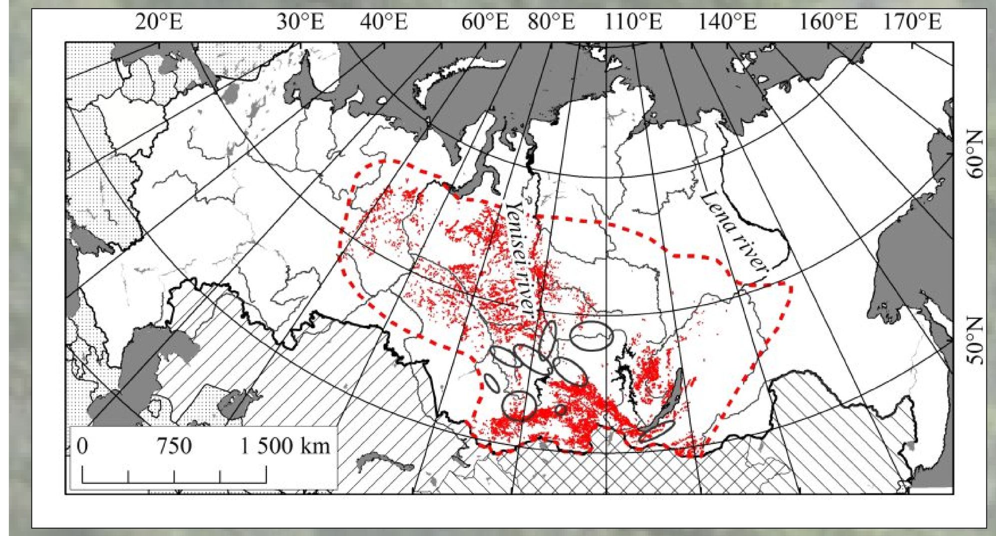
In the southwestern part of USA drought-induced mortality of Pinus edulis was documented for an area of over a million hectares (Van Mantgem et al., 2009).

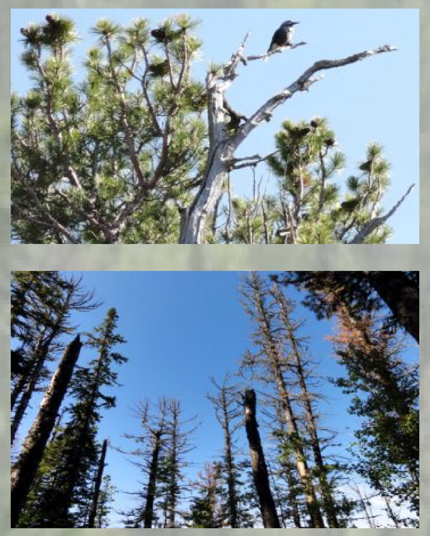
In Russia decline and mortality of "dark needle conifers" (DNC: Pinus sibirica, Abies sibirica and Picea obovata, Picea abies, Picea ajansis, Abies nephrolepis) were reported from the western border to the Russian Far East (Man'ko et al., 1998; Pavlov et al, 2008; Chuprov, 2008; Zamolodchikov, 2011;Voronin, 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 begun? 2) What was a temporal and spatial pattern of mortality? How did mortality relates to topographic features? 3) How mortality connected with climate variables?

STUDY AREAS

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





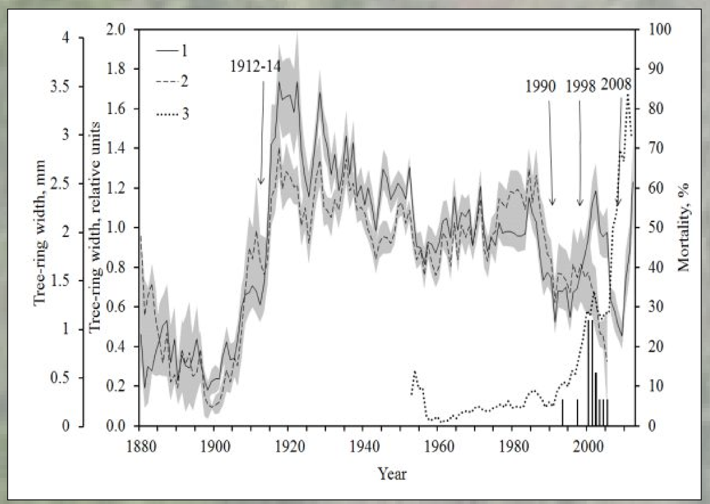
METHODS

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

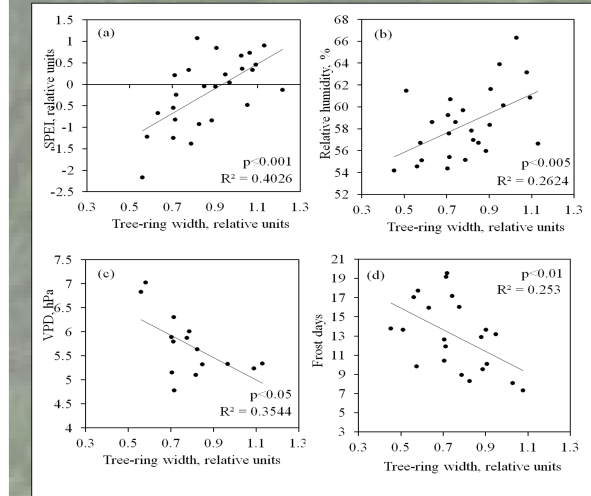
RESULTS

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 decline: relation with climate variables

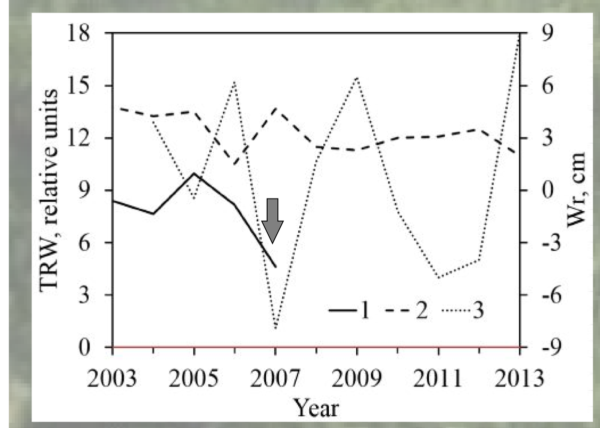


Relationship between TRW and climate variables. a – SPEI, (b) –relative humidity, (c) –vapor deficit, (d) – late frost.

TRW was positively correlated with air humidity and negatively with vapor pressure deficit and drought index. Negative correlations were observed between TRW and late frosts.

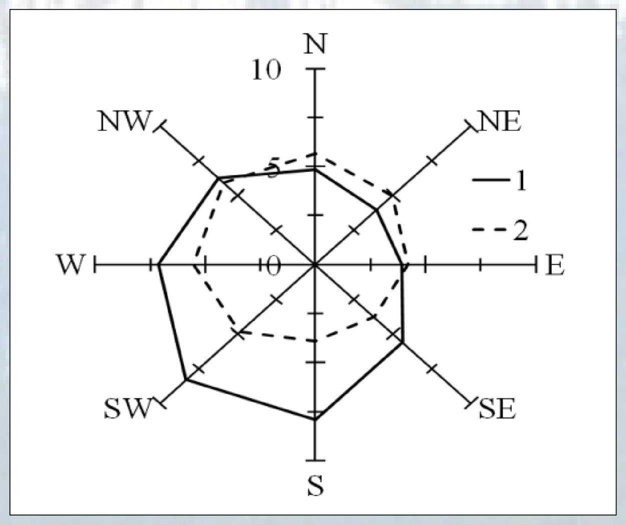
DNC sensitive to both, soil and atmospheric droughts.

GRACE data

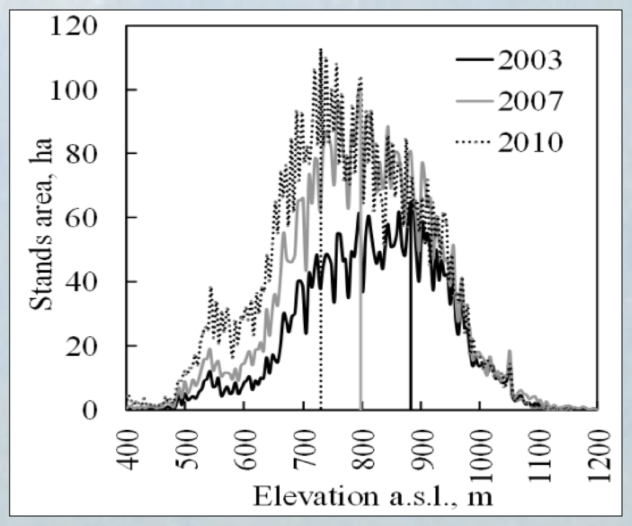


Tree-ring width (TRW) dynamics of (1) dead fir stands, (2) alive fir stands, and (3) residual water mass (Wr). The year of Wr minimum (2007) coincides with a date of stands mortality. In general, there is negative correlation between TRW and water mass derived from GRACE gravimetric data.

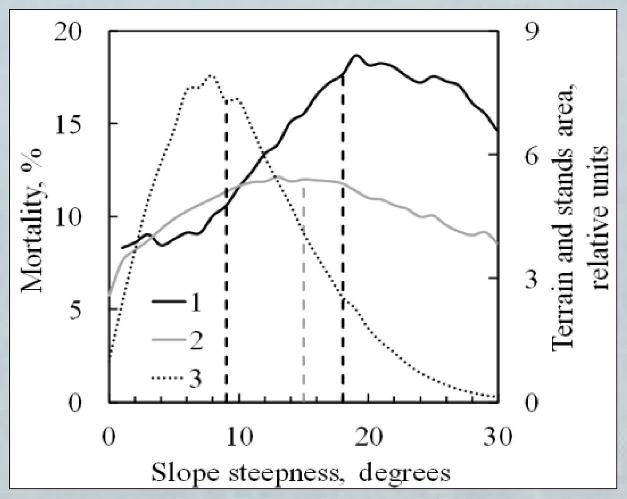
Abies sibirica and Pinus sibirica : relationship with relief features



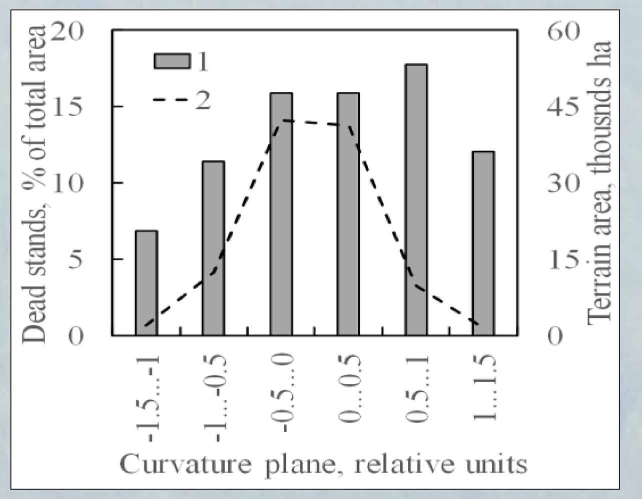
Azimuthal distribution of stands mortality. 1 – dead stands, 2 –all stands.



Elevational distribution of dead (1) and all (2) stands

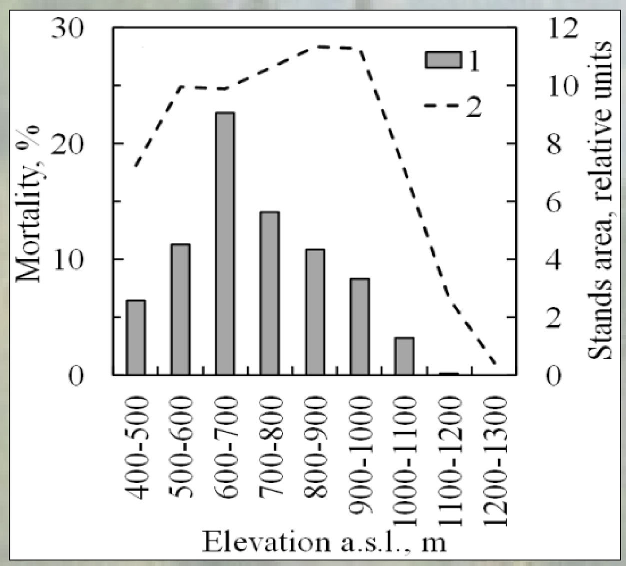


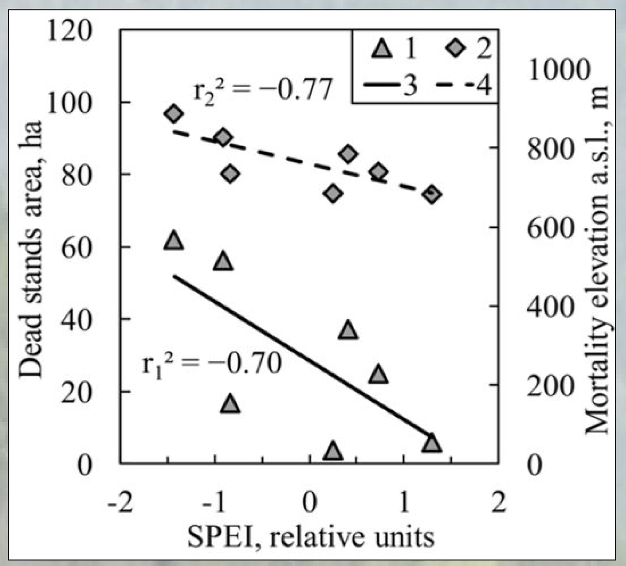
Stands mortality with respect to slope steepness. 1 – dead stands, 2 – background stands.



1 – stands mortality with respect to slope curvature (concave/convex), 2 – all terrain.

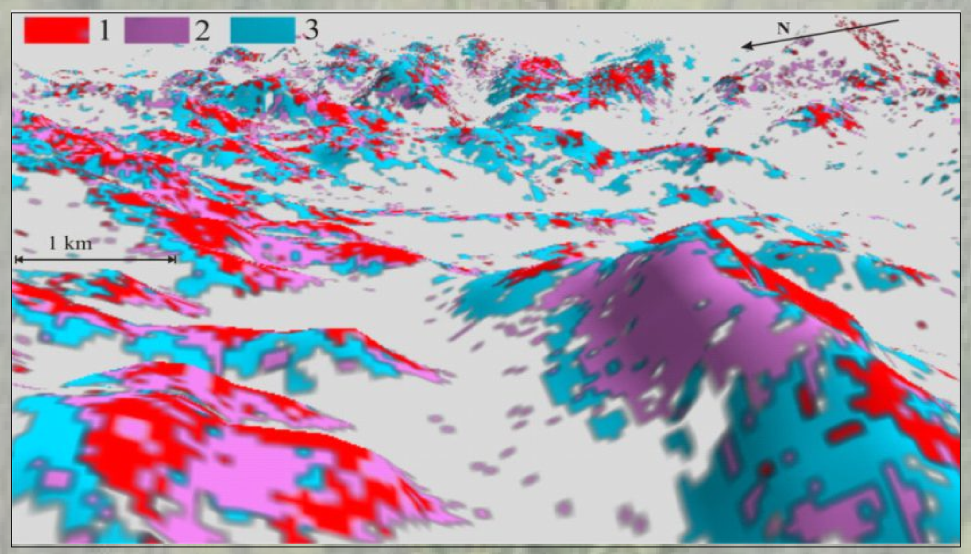
Stands mortality was observed on the areas with a maximal water stress risk.





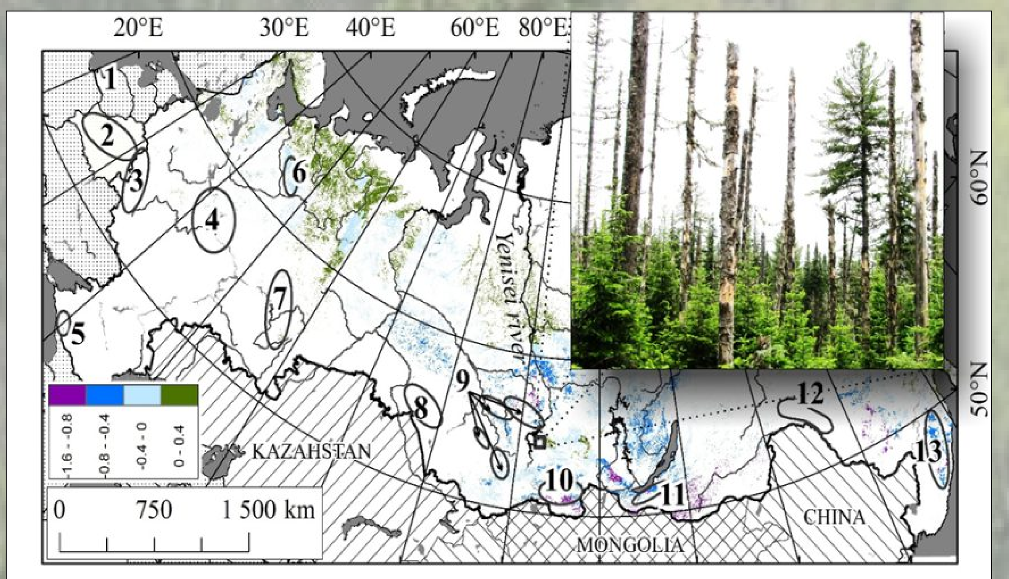
Dead stands area (1, r_1^2) and mortality elevation limit correlations with SPEI (2, r_2^2). 3, 4 – linear regressions of the dead stands area and mortality elevation limit, correspondingly.

Elevation boundary of tree mortality was limited by gradient of precipitation.



Elevational distribution of dead stands in 2003 (1), 2007 (2) and 2010 (3).

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.

Stands decline is observing mainly within ecotones between DNC and broadleaf or forest-steppe, within marginal parts of DNC areal.

Within areal stands declining at the relief features with a maximal water stress risk

Geographically those areas coincided with a low SPEI values (a drought zones).

Why DNC (fir, Siberian pine and spruce) are so sensitive to drought?

Forest composed by fir, Siberian pine and spruce had a high LAI value (up to 16-18). For comparison: LAI of Scotch pine stands are about 5-7.
High LAI caused also DNC sensitivity to "air drought".

Water-stress weakened trees become sensitive to bark beetles and fungy.
A synergy of water stress and biotic agents caused tree mortality.
Also primary cause of decline and mortality was a water stress.

Scenarios of climate changes are likely to include further increases in drying, frequency and severity of droughts in some forested areas (e.g., IPCC, 2014; Sterl et al., 2008).
It will lead elimination of Pinus sibirica and Abies sibirica within part of its areal and substitution of these species by water-stress tolerant species (e.g., Pinus silvestris, Larix sibirica).

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 areal, e.g., within DNC - forest-steppe ecotones.
Within inner part of Siberian pine and fir areal 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 areal will be replaced by more drought-resistant species (i.e., Pinus silvestris, Larix sibirica) species.

ACKNOWLEDGEMENT

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