

INFLUENCE OF CLIMATE CHANGE ON GROUNDWATER LEVEL AND STATE OF PINE PLANTATIONS ON SANDS OF CASPIAN LOWLAND

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Abstract

The influence of changes in groundwater level dynamics on the state and growth of old-aged pine plantations growing in the Caspian lowland in the barchanic depressions of the Naryn sands is studied. The main reason for the deterioration in the physical condition of pine trees is the yearly decline in moisture consumption from groundwater due to the earlier seasonal separation of the lower tier of the root systems from the upper boundary of the capillary fringe of groundwater. This is caused by the climatogenic trend of the decrease of groundwater level since 2005. The drying of the weakened trees is hastened by other environmental factors such as the burial of the upper tier of root systems, infection of tree trunks by Buprestidae, partial tearing of horizontal conducting roots of the upper tier by hurricane winds.

Keywords: tree plantations, *Pinus sylvestris*, barchanic sands, groundwater level, tree drying

1. INTRODUCTION

The climate change can significantly infer the biogeocenotic relationship between different components of forest ecosystems. In arid regions, the most substantial impact can be mediated by the climatogenic change in the abiotic part of ecosystem such as rise and decrease in ground water level, an increase in the deficit of available soil moisture, increase in the duration of annual summer droughts and winter thaws, hurricane winds etc. (Ga'el 1952; Ga'el and Smirnova 1999; Sapanov 2005, 2006).

The significant climatogenic transformation of natural conditions of the Caspian Lowland was revealed in our previous studies, namely, the change in the level of water in natural and artificial water bodies including the Caspian Sea (Sapanov 2007, 2010) and groundwater level (Sapanov 2003; Sokolova et al., 2000; Sizemskaya 2013). These changes can undoubtedly influence the living nature. This study is focused on the mechanism of the influence of groundwater table dynamics in Naryn sands (the Volga and the Urals interfluvium) to the state of pine plantations located in the barchanic depressions between sand ridges.

2. MATERIALS AND METHODS

Naryn sands have an area of 0.5 mln. hectares and occupy the northwestern part of the vast (about 4.5 mln. hectares) Volga-Urals sand massif.

The study area belongs to the semidesert zone with sharply continental climate which is characterized by the pronounced air temperature contrasts between summer and winter as well as between day and night. During the winter season, under the impact of anticyclones the weather is cold and with clear skies. The summer season is hot and dry. The mean January temperature can be as low as -12°C whereas the mean July temperature can reach +26°C. The absolute minimum is -43°C absolute maximum is +44°C. The negative temperatures are set in the mid-November and are held until the end of March (Ga'el 1952).

The study area belongs to the zone of insufficient moisture, mainly due to low precipitation (300 mm) and relatively high temperatures in summer which promotes the intensive evaporation (about 1000 mm). The specific feature of the weather conditions is instable atmospheric humidity. Low snowfall

and dry winds are very typical of this area. The maximum mean annual precipitation was registered in 1976-1995 and amounted to 305 mm. During the last decade (2005-2015), the mean annual precipitation is 256 mm with amplitude from 185.1 to 343.6 mm. The snow cover is usually formed in the second half of November and lies until March. The depth of the snow cover in snowy winters reaches 40 cm, and in snowless winters it does not exceed 12 cm. The mean snow cover depth is 14-28 cm. The most snowy period is from January 20 to March 20. Spring snowmelt starts rapidly, however, surface runoff in the study area is not observed. The replenishment of groundwater occurs mainly during the spring snowmelt, while the precipitation of the warm period is immediately spent for evapotranspiration (Technical Project ... 1953; Ga'el and Smirnova 1999).

Macrotopography of the Naryn sands has typical features of the ancient alluvial deltaic region with valley-shaped depressions (ashiks) alternated with the hilly strips of sands (naryns). The width of naryns is 5-20 km and length is 20-30 km or more. The width of ashiks is about 10 km. Sandy ridges are represented by hilly-barchan mesotopography. The height of the sandy dunes in the central part can reach 15-17 m, at their periphery the height is about 3-5 m. Between barchans, the so called blowouts are located (Technical project... 1953).

Under sand dunes, the fresh non-pressure groundwater of bicarbonate-calcium content (0.2-0.5 g/l) lies as the unified horizon. The depth of groundwater is 1.5-3 m in the blowouts up to 10 m at the top of barchans.

Barchan basins (blowouts) have the best conditions for growing forests in the region. Here, the natural woody vegetation grows such as some species of poplar, silver berry (*Elaeagnus oxycarpa*), alder, buckthorn (*Rhámnus cathártica*), dog rose, Caspian willow and others. The tree plantations are also located within these small depressions including the Scots pine (*Pinus sylvestris*) which has been grown here since the XIXth century. During the last century, some hundreds hectares of pine plantations were created which represent the isolated patches repeating the shape of the bottoms of barchanic deflation basins.

The object of our study was these uneven-aged pine stands. The plots with healthy and dying pine stands were selected and then studied. At the plots, a general description and entire taxation were carried out. The timber core samples were taken. The auger holes were drilled to the depth of groundwater and soil samples for moisture content measurements by gravimetric method were taken from each 10 cm. The depth of stable groundwater level was measured. In the vicinity of two dead trees, the 3-m deep soil trenches were dug. Soil morphological description, soil and root sampling was performed for further analyses. The results of hydrological observations of groundwater level were the courtesy of Zhaykhydrogeologiya LLP.

3. RESULTS

Scots pine (*Pinus sylvestris* L.) is a coniferous evergreen tree which can reach a height of 35-40 m. Crown of young trees is conical, in adults - rounded, in old age - umbellate or flat. The lifespan is 150-200 years. In cultures, their age decreases. In the Naryn sands, the pine plantations are represented by small isolated patches within the barchanic basins. Here, their age can reach more than 100 years (Fig. 1).

The development of these stands is typical. The older the trees, the less is their number in the basin. The biomass of the trees at the margins is larger than that located in the central part of basin. The crown shape loses its conicity with age. Pine reproduces by seeds. In the studied conditions, there are sporadic self-sowing trees outside the plantations.

Pine has a very plastic root system which develops in accordance with the nature and structure of the soil, which makes this species irreplaceable on dry and poor sandy soils. In the studied conditions, the pine forms a two-tiered root system. The first tier of roots is located in the upper horizon of sandy soil and the second on is in the capillary fringe of groundwater. Such an arrangement of the root system allows the pine to use the surface soil moisture accumulated during the cold season as well as the groundwater moisture (Fig. 2).



Figure 1. The old-aged patches of pine in the barchanic basins of the Naryn sands (2016)

It is noteworthy that the lower tier has a small thickness (30-40 cm) in the form of so-called root beards. Two tiers of root systems are connected by transit thick anchor roots, which are located in a highly desiccated soil horizon.

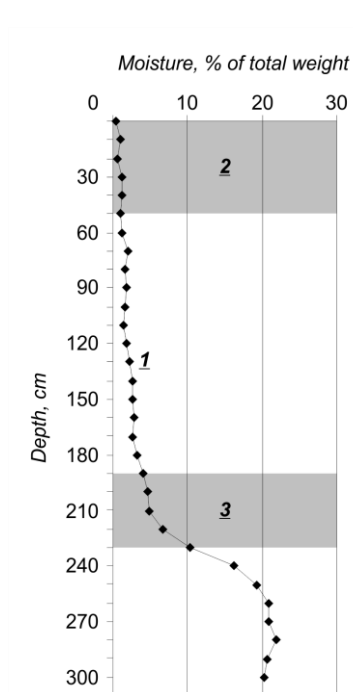


Figure 2. Soil moisture content (1) in June 2016 and the location of roots in the upper (2) and lower (3) tiers.

Visually, the main part of trees in pine patches has a healthy appearance as they have intense green color of needles, no drying branches as well as pests of trunks and needles. However, in some basins there is a partial drying of the pine. The typical scenario for the death of trees is as follows: gradual lightening of needles → general thinning of the crown → gradual weakening (Fig. 3). On the branch, the drying of the needles occurs from the petiole to the apex.



Figure 3. The desiccated pine in the Naryn sands (2016)

It was shown that the patches with the healthy pines has the groundwater level in July 2016 at 2 m or shallower. In other words, such basins are deeply imbedded in the sandy ridges and their bottom is located closer to the groundwater table. The indicator of good moistening here is the presence of reeds and Caspian willow.

The vitality of the pine deteriorates (down to the lethal outcome) mainly in the basins with deep groundwater table (more than 3 m). The excavation of the root systems of the dead pine trees and the determination of soil moisture under them confirmed this thesis. As early as in July (2016) the second tier of root system was located above the capillary fringe at the depth of 190-230 cm, with a groundwater level at a depth of 3 m (Fig. 2). This arrangement of roots in relation to the groundwater table in the middle of the growing season is very dangerous for trees since the moist sand in the root layer is slightly connected with groundwater and is unlikely to provide the growing trees with enough water. It is this mechanism that interrupts the feeding of roots from groundwater. By the autumn, with an even deeper seasonal groundwater level due to general evapotranspiration, the upper boundary of the capillary fringe will obviously totally break away from the absorbing roots of the second tier. It is worth noting that by this time all moisture from the upper root zone of sandy soil accumulated during the cold period of the year is completely consumed by forest.

Analysis of the general dynamics of the groundwater level in Naryn sands (for 12 wells) showed a significant change in its trend in recent years manifested in a sharp climatogenic annual decrease since 2005 (Fig. 4). If this trend persists, the capillary fringe will break away from the root system of pine trees during the next growing seasons earlier and earlier.

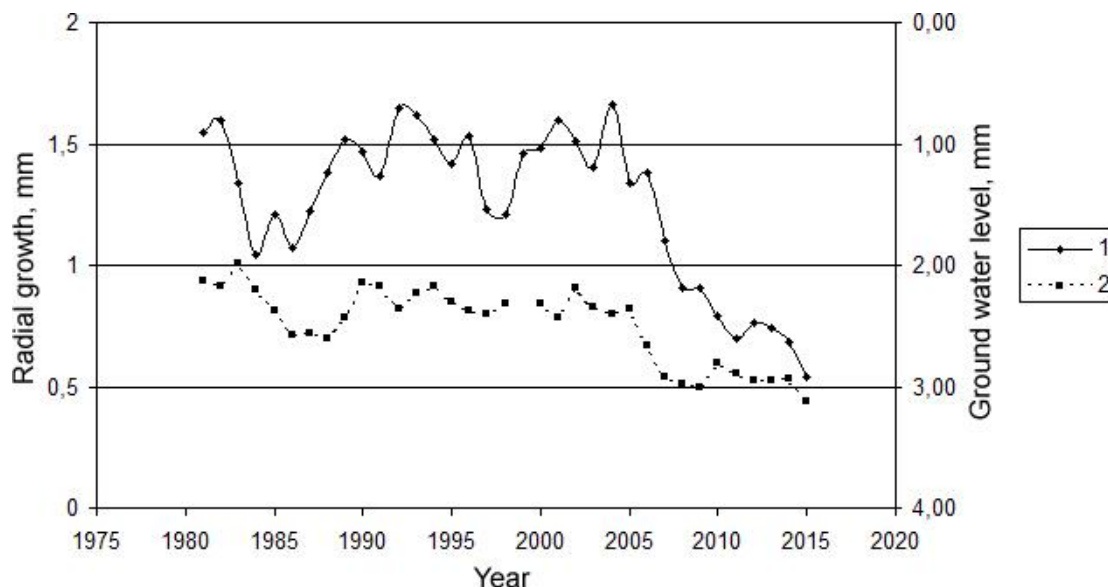


Figure 4. The dynamics of groundwater level (1) and mean annual radial growth of pine (2) in the barchanic part of Naryn sands.

4. DISCUSSION

How do trees react to such a decrease in groundwater level? It was revealed that at all patches the overall development of both visually healthy and dying trees differs very slightly judging by the dynamics of the annual radial growth (Fig. 5).

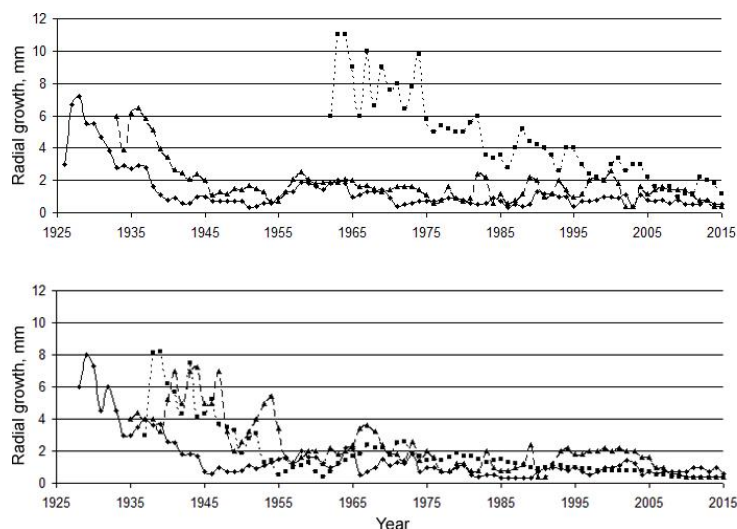


Figure 5. The dynamics of radial growth of healthy (1-3) and dried-up (4-6) pines in different patches.

At a young age, the radial growth of trees planted in the beginning or in the middle of the XXth century can reach more than 10 mm, then it rapidly decreases and varies within several millimeters. As Figure 5 shows, the trees with a radial growth of less than 2 mm can live for many decades. At the same time, in the last decade (~2005-2016), the radial growth of trees deteriorated sharply independent of their age, state and development grades and became less than 1 mm.

This indicates that since this time the pine has begun to experience the strongest stress caused by a decrease in water uptake due to the lowering of the groundwater table.

The most significant proof of the relationship between the state (radial growth) of a tree and the groundwater level is the statistically significant negative relationship between these parameters for 1981-2015 ($r = -0.81$, $P > 0.01$). In other words, the deeper the level of groundwater, the worse the growth of trees becomes (Fig. 4). Moreover, the figure shows an abrupt decrease in the mean radial growth of trees in 2005-2015 following a steady decrease in the groundwater level by 0.77 ± 0.04 m.

It should be noted that the strongly weakened and dry pines had signs of negative impact of other environmental factors on them. First, many tree trunks and near-trunk rings are covered with fresh aeolian sand (Fig. 6.1). This aeolian layer can reach 100 cm and cannot be penetrated by roots. Therefore, all moisture of atmospheric precipitation, which is deposited here, is subsequently spent for physical evaporation instead of water supply for trees.



Figure 6. The secondary factors of the death of pine plantations: 1 – burial with sand; 2 - infection of tree trunks by pests (Buprestidae); 3 - tearing of roots during the windfall.

Second, a significant number of weakened trees is infected by secondary stem pests (Buprestidae). The larvae of the Buprestidae destroy the living tissues in the sub-bark area in the bast area and can completely block and stop the transport of sap with nutrients in the trunks, thereby worsening the work of the cambial layer of the tree (Fig. 6.2).

Third, the windfalls indicate that the hurricane winds can tear up the surface conductive roots in the upper horizons of the soil due to a strong swinging of the trunk under such a wind load (Fig. 6.3).

5. CONCLUSION

The old-aged cultures of pines in the Naryn sands are the unique tree plantations that create the exceptional pine-patchy landscape in the interfluvium of the Volga and the Ural rivers. At present, the pronounced deterioration of the state of these tree stands occurs, regardless of their age and stage of development, which is recorded by the decrease in the annual radial growth, crown thinning and the lightening of needles.

The main reason for the deterioration in the physical condition of pine trees is the yearly decline in moisture consumption from groundwater due to the earlier seasonal separation of the lower tier of the root systems from the upper boundary of the capillary fringe of groundwater. This is caused by the climatogenic trend of the decrease of groundwater level since 2005. The drying of the weakened trees is hastened by other environmental factors violating the water regime in the aeration zone. They include: (a) the burial of the upper tier of root systems leading to the partial inaccessibility of water coming with the spring runoff for water supply of the tree; (b) infection of tree trunks by Buprestidae that can ring the sub-bark area of the tree trunk and thereby worsen the transport of nutrients and the work of the cambial layer; (c) hurricane winds which can tear up the horizontal conducting roots of the upper tier.

In order to preserve pine ecosystems in the Naryn sands, it is necessary to repetitively conduct here the scientifically based forestry works.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research (Project № 18-04-00246) and Program “Biological Resources of Russia”.

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