Thaw depth variation with plant succession after anthropogenic disturbances, Central Yakutia

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ABSTRACT: This paper discusses thaw depth variation throughout re-colonization stages of disturbed permafrost landscapes in two types of environment: on loamy and sandy deposits of high terraces, on both banks of the Lena River. Observed changes in the dynamics of seasonal thaw depth were found to occur in definite intervals of successional stages: herb, shrub-birch, larch (pine) – birch, and larch (pine).

1 INTRODUCTION

In Central Yakutia, permafrost landscapes are subject to strong anthropogenic impact where large-scale disturbances result from forest harvesting, frequent wildfires and land clearance for agriculture. The natural re-colonization (self-regulation) of biota in the forest cuts and burns in the middle taiga subzone of Yakutia have been extensively studied by foresters (Timofeev et al. 1994). The results show that the self-regulation of disturbed permafrost landscapes develops naturally by stages, and occurs with successional changes of biota over 130 years. Recovering successions are characterized by specific ground thermal conditions. Specific relationships between successional variation, summer thaw depth and permafrost temperature in the forest cuts of the Umaibyt monitoring site have been suggested by Fedorov (1985).

This paper discusses the thaw depth variations throughout the re-colonization stages of disturbed permafrost landscapes. The landscapes studied are located on the high terraces of the Lena River (Fig. 1) and are underlain by loamy and sandy deposits. The study area is located in a continuous permafrost region where the frozen ground is 300 to 500 m thick and its temperature is between −2°C and −3°C. The rigorous permafrost conditions explained by the following climatic parameters: mean annual air temperature is −10°C to −11°C; freezing index is −5400 to −5800 degree-days; thawing index is −1600 to −1900 degree-days; mean annual precipitation is 240 to 260 mm (160 to 180 mm of which is summer precipitation). On the high terraces of the Lena River, vegetation development on undisturbed flat well-drained sites is characterised by Laricetum vacciniosum and Laricetum herboso-vacciniosum on permafrost taiga pale soils, and Pinetum arctostaphylosum on permafrost turf and poor podzolic soils.

The first study area is located on the east bank of the Lena River, 50 km southeast of Yakutsk (the Yukechi monitoring site maintained by the Permafrost Institute). The second is located 25–35 km north of Yakutsk on the west bank of the Lena and includes two monitoring sites, Neleger and Spasskaya Pad.

At Yukechi and Neleger, community recovery in the forest cuts of varying age takes place on a loamy substrate, while at Spasskaya Pad, it occurs on sandy soils. The results of the field survey indicate that patterns of thaw depth dynamics through successional sequences are virtually identical for Yukechi and Neleger, which have a similar substrate as well as forest type (Fig. 2: a2, a3).

Moreover, when compared with data from earlier observations by Fedorov (1985) at the Umaibyt site, 90 km southwest of Yakutsk (Fig. 2: a1), the thaw depth variation at the two sites closely parallels that at Umaibyt where the vegetation is Laricetum mixtoherboso-vacciniosu, and the soil is loamy. The Umaibyt site characteristics do differ slightly from those at Yukechi and Neleger however, due to a longer period of shrub exclusion and grass-cover decline during the birch stage.

Generally, the results obtained on relative seasonal thaw depth variation from sites with successions characterised by recovery from anthropogenic activity can be used to estimate the dynamics of permafrost-landscape conditions in Central Yakutia. This enables...
the prediction of their variation after disturbance. This method is well-known in permafrost science (Tyrtikov 1974, Fedorov 1985, Stashenko 1987, Moskalenko 1991), but has not been widely used in further research.

An understanding of the evolution of permafrost characteristics associated with vegetation succession enables enhanced predictions of the development of the permafrost environment to be made. This is particularly important for predicting the dynamics of the upper permafrost following disturbance.

2 METHODOLOGY

The original material was obtained through a permafrost-landscape survey at the Umaibyt site in 1981 and 1982 and at Yukechi, Neleger and Spasskaya Pad in 2000. The landscape survey covered the natural and recovering facies of the community and included a detailed description of the composition of tree stands, undergrowth, shrub and herb-shrub layers, and moss-lichen cover.

The plant successions were studied at sites totalling 42 km² in area. These sites, similar in lithology and geomorphology, were previously occupied by primary vegetation. In total, 88 points from plant successions of various age in the cut and burnt areas were described. Of these, 30 points were at Umaibyt, 18 at Yukechi, 18 at Neleger, and 22 at Spasskaya Pad. The ages of the successional facies were determined in the field by measuring the annual rings of trees and shrubs. This was then verified by data from local forestry organizations. The age of wildfires was determined from the darkened rings of surviving trees. Seasonal thaw depths were measured at all observation points.

The data on seasonal thaw depths were organized according to the age of the vegetation recovery stages, whilst the seasonal thaw depth variations in anthropogenic successions in Central Yakutia are presented graphically as relative values.

3 RESULTS

As the relative recovery of disturbed landscapes and thaw depth variation in loamy and sandy substrates are distinct, the description of the successional stages will be discussed separately, according to their appropriate lithological type.

3.1 Loamy substrate area

Within the loamy substrate, the depth of seasonal thaw increases steadily during the early disturbance recovery period, when strong perturbations still prevail. As a result, the upper layer of permafrost thaws, resulting in an increase in the moisture content of the active layer. The moisture content in the thawed layer may remain high for the first few years after disturbance because of the reduced moisture loss by transpiration. During this stage the surface is colonised by herbs as well as by shrubs. The herb stage usually lasts 5–6 years, but may be prolonged by up to 10 years in the absence of permafrost. Increased values of seasonal thaw depth are observed during the herb stage, being 1.3–1.5 times those in the original, undisturbed sediments.

In areas recovering from ploughing, the herb stage may be much longer depending on the field size,
moisture content and insolation (shading) conditions on the surface. The depth of seasonal thaw in these locations is 1.7–2 times greater than in the original sediments. On the clear-cuts, the ground cover dies off gradually and herbaceous plants invade the area during the early stage of recovery. On surfaces that have been burned, pioneer species and shrubs become established within the first few years after the fire. Tree seedlings may appear on the disturbances in the first year or two, and larch is sometimes established in the fourth year after being cut or burned. In those areas where the trees have been cut in wintertime, birch seedlings can appear in the following summer. Five to eight years after disturbance, severe competition between the herbs, shrubs and tree saplings occurs. From this point onwards the depth of thaw begins to decrease. As melting of the upper layer of permafrost ceases and the moisture accumulated in the lower part of the active layer is exhausted, the shrubs begin to gradually disappear and the density of the grass cover decreases.

By the twentieth year following disturbance the depth of the summer thaw in the young birch stands has decreased notably, by 0.1–0.3 m, compared to the former maximum. There is also a significant decrease in thaw depth in the fields with 20 years of tree growth, where the depth of thaw is up to 0.5 m less than in the fields with the meadow vegetation. In general, thaw depth decrease is caused by the rapid growth of saplings and the appearance of new seedlings, despite the grass cover steadily becoming thinner.

30–40 years after disturbance, in the birch stage with a mixture of young larch trees, the depth of seasonal thaw increases when the crown closure is 0.1–0.3. This increase is due to the exclusion of shrub vegetation and a reduction in grass-cover. When the crown closure is 0.4 or greater however, no notable increase in thaw depth is recorded. At the Umiabut site, an increase in thaw depth associated with shrub disappearance and grass-cover reduction is observed 30–50 years after the initiation of disturbance.

40–50 years after disturbance, the range of young larch begins to expand within the cut areas. On the burns and burned cuts, larch growth dominates over birch during this period. A further decrease in thaw depth occurs. During this period, the shrub layer virtually disappears from the undergrowth, with occasional shrubs of spirea, dog rose and, very rarely, willow remaining.

The depth of seasonal thaw is shallowest 70 years after disturbance, when shading by the tree canopy is greatest. Because of the dominance of larch over birch, the crown closure is 0.5–0.7 in mixed stands and 0.8–0.9 in pure larch thickets. A sparse ground cover of mountain cranberry or a continuous litter is typical. Pyrula and scattered patches of moss and lichen also appear.

Some increase of the active layer thickness, reflected in thaw depth, occurs in the stage with 90–100 year old Laricetum vacciniosum. This is due to the self-thinning of the tree stands. In the final stage of Laricetum vacciniosum recovery (100 years or older), the depth of seasonal thaw is virtually identical to that in the original forest.

3.2 Sandy substrate area

The dynamics of thaw depth and vegetation succession on a sandy substrate was investigated at the Spasskaya Pad site (Fig. 2: b4, b5). The vegetation on flat sand-ridges comprises Laricetum arctostaphylos-vacciniosum. Well drained areas of higher elevations are colonised by Pinetum arctostaphylosum. Both forest communities were characterised by a number of successional stages following disturbance, although the dynamics of thaw depth is somewhat different from the loamy deposits sites.

Because the sand ridges are ice-poor, the initial stage of perturbation lasts 3–5 years in both the larch and pine forests. Depth of thaw increases by a factor of 1.5 after tree cutting. As the ground cover dies out, Chamerion angustifolium, Artemisia tanacetifolia and rare patches of Carex duriuscula appear.

A few years after the cutting of the larch forest, larch seedlings appear on relatively dry surfaces, while birch seedlings grow on mesic sites. In the pine cuts, pine seedlings appear, usually occurring when a snowy winter rapidly gives way to a moist spring.

A notable decrease in thaw depth occurs 20–40 years following the cutting of larch and birch forests and between 30–40 years after the cutting of the pine forest. These periods are characterized by the rapid growth of trees. There is some increase in thaw depth during the stage of self-thinning, 50–60 years after tree cutting. As reported by forest scientists (Timofeev et al. 1994), the next rapid height growth of larch trees occurs during the 70–80 year period, whilst pine trees grow in diameter and their canopy expands at 70–90 years of age. Shading by the forest canopy due to the increased height of the larch and branching of the pine has a negative effect upon thaw depth.

4 CONCLUSION

The disturbed sites with loamy deposits undergo three cycles of thaw depth increase. During the initial perturbation stage (3–10 years after disturbance), the shrub exclusion and grass reduction stage (approximately 40 years) and the self-thinning stage (90–100 years). The sites also indicate two cycles of thaw depth decrease. During the growth spur of young trees...
(approximately 20 years after disturbance) and the thickening of tree stands (about 70 years).

The recovering communities on sandy deposits show two cycles of thaw depth increase. During initial perturbation (within 3–5 years after disturbance) and self-thinning of tree stands (50–60 years). They also undergo two cycles of thaw depth decrease. During rapid growth of young trees (20–40 years after disturbance in the larch forest and 30–40 years in the pine forest) and during the next period of rapid growth of larch and rapid branching of pine (70–90 years).

Overall, thaw depth variations during vegetation recovery is less dynamic in the permafrost landscapes on ice-poor sands compared to those overlying ice-rich loamy substrates.

In conclusion, it has been demonstrated that the successional method presented in this paper can provide a clearer understanding of permafrost dynamics following landscape disturbance. It is recommended that the application of this method be expanded to research in other permafrost regions.

REFERENCES


