Influence of freezing processes on the vegetation of Sakhalin swamps

N A Tsarenko¹, I F Skirina² and F V Skirin³

¹ Botanical Garden-Institute FEB RAS, Vladivostok, 690024 Russia
² Pacific Institute of Geography FEB RAS, Vladivostok, 690041 Russia

E-mail: ntsarenko@mail.ru

Abstract. Herewith the current characteristics of the bog vegetation on the Chaivo spit in the north of Sakhalin are outlined. The many-year surveys have discovered icy permafrost at a depth of 45-70 cm which leads to the formation of annual and perennial migratory pingos. Herewith a brief description of the changes of the pingo vegetation is provided, it has been discovered that the process of lichen growth on the pingos is of selective nature. It has been noticed that some pingos on the bogs of the Chaivo spit have increased in size, which obviously demonstrates the process of replacement, firstly, of mosses by lichens, which in their turn are replaced by herbs and mall shrubs, i.e. pingos on different phases of development can be found. During the period of the surveys, it has been identified that the share of perennial pingos covered with lichens has increased.

1. Introduction

Migratory pingos are relatively widely spread on the territory of Europe, Asia, and North America. A detailed overview of the history of the surveys, the genesis, the geographic distribution, the composition and characteristics of pingoes in the European north of Russia, the north of West Siberia, Mid-Siberia and Yakutia, Trans-Baikal, Altai as well as in Mongolia, Sweden, Norway, Finland, Spain, Canada and in Alaska is provided in a survey by Y K Vasilchuk and co-authors [1]. They identified quite fast changes in the distribution of migratory pingos in the second half of the 20th century and the beginning of the 21st century followed by a decreasing the areas occupied by pingos in the arctic and subarctic peatlands which can probably be related to global climatic changes.

The share of bogged lands on Sakhalin is 16.5% of the whole territory, 86.6% of them is oligotrophic bogs [2]. Bogs with the formation of migratory pingos are of particular interest. Despite Sakhalin is located southerly to the boundary of permafrost it can occur here in particular spots. In the middle of the last century, a general study of bogs pingo vegetation structure was carried out by N V Vlastova [3], which discovered the influence of freezing processes in the peatlands of Sakhalin on the change of bog vegetation. This issue remains topical nowadays due to the change of the climate conditions influencing the direct formation of such pingos. The growth, development, and following degradation of such pingos may result in a change of the vegetation of the bogs in general, moreover considering the fact that many of them represent mass bird nesting areas or reindeer pasture lands in the north of Sakhalin [4].

The surveys are aimed at studying the current state of the bog vegetation with distinct migratory pingos on the example of the Chaivo spit located in the northwest of Sakhalin (52°31’ N, 143°16’ E). The spit separates Chaivo bay from the open part of the sea of Okhotsk. It forms a part of the North-
Sakhalin lowland with an average width of 2.68 km and develops a low sand coastal terrace with a prevailing elevation of 2-4 m. The surface of the spit is formed by a set of multiple ancient barrier beaches separated by swales that are bogged and are often occupied by shallow fresh-water lakes or narrow streams flowing out of the lakes. The occurrence of the spit in its present form is assumed to have been caused by the rise of the ocean level in the Mesoholocene about 3200 years ago. The formation of a narrow spit with a width up to 1 km took place about 500-1000 years ago [5].

2. Methods

The flora of the Chaivo spit was surveyed in July-August in 2006, 2015, and 2020 (figure 1) by the route method [6], and studies of the soils were carried out in the same months from 2008 to 2013.

![Figure 1. The study area.](image)

The vascular plant species were identified according to “The Vascular Plants of the Soviet Far East” [7]. The lichen herbarium materials were prepared in the Centre for Landscape Ecological Investigations of the Pacific Institute of Geography of the Far-East Branch of the Russian Academy of Science (Vladivostok). The lichens were identified by the standard microscopy technology as well as by the colour reaction method with 10% KOH, Ca(ClO)₂, KOH + Ca(ClO)₂, IKI, [C₆H₄(NH₂)₂], UV-glowing in the ultraviolet. The herbarium specimens are stored in the herbarium of the Pacific Institute of Geography of the Far-East Branch of the Russian Academy of Science (VGEO). The nomenclature of the taxa is stated according to the updated digital resources “The Consortium of North American Lichen Herbaria” (CNALH) [8], CABI Bioscience Databases [9], Mycobank database, Fungal database, nomenclature, and species banks [10] and studies of separate taxonomic groups [11, 12]. The soils were studied in OOO Moscow Centre for Certification and Environmental Monitoring of the Agrochemical Service. The pH was determined by potentiometric method in soil-water and salt extracts [13] with an ion meter, I-160; the ash content – according to GOST [14], the content of the exchanged calcium and magnesium in the soil by the method of Shellenberg (a GOST number is not issued), the gross content of nitrogen, phosphorus and potassium – by the acid digestion method (a GOST number is not issued).
3. Results
Upon the results of studies, the following has been identified on the Chaivo spit: 54 species of bryophytes, 70 species of lichens, 99 species of vascular plants. The surveyed area belongs to the circumboreal flora area which is confirmed by the species diversity of the Cyperaceae Juss., and Ericaceae Juss. families. The vegetation of the spit is represented by two major plant formations: sparse larch forests with dwarf cedar pine on the barrier beaches and shrub-sedge-sphagnum bogs in the swales. There is a range of large and small stable lakes in the area. Carex caespitosa L. that forms large tussocks grows immediately at the water border as well as other species, such as Comarum palustre L., Carex cryptocarpa C.A. Mey.

Organogenic soil horizons in swales are formed by peat with an average ash-content of 3.9-4% which allows recognizing the surveyed bogs as related to oligotrophic type. The soils have a low degree of decay of the near-surface aquifers. They have low pH with very high hydrolytic acidity, the absorbing complex of the soils has low saturation with calcium and mostly low saturation with magnesium. The soils have medium content of nitrogen, low content of phosphorus, and very low content of potassium. The grain-size distribution of the mineral horizons uncovered at a depth of about 1 m is classified as light sandy loamy soils: the content of physical sand (79.2%) exceeds the content of physical clay (20.8%) nearly by four times, small sand with a grain size of 0.05-0.25 mm prevails (44.8%) among separate fractions. The surveys that were carried out in August in different years discovered permafrost at a depth of 45-60 cm causing the formation of migratory pingos of different sizes (from 40-60 cm to 2-3 m long and 25-60 cm high), from round to elliptic in shape.

Among shrub species, Pinus pumila (Pall.) Regel and Duschekia fruticose (Rupr.) Pouzar (figure 2) can be found on barrier beaches adjacent to swales and large pingos.

![Figure 2. Bogs with migratory pingos on the Chaivo spit.](image)

The survey has demonstrated that the surface of large pingos is occupied by such small shrub species as Rubus chamaemorus L., Empetrum sibiricum V. Vassil., Rhodococcum vitis-idaea (L.) Avror., and Ledum palustre L., the height of the latter reaches 30-40 cm. Upon moving further onto the bog, it can be seen that the pingos are numerous but most of them are of small size (d = 40-45 cm). During the surveys made in 2006 numerous migratory pingos were discovered, most of them were small: up to 30-40 cm in diameter with a height of 25-30 cm (figure 3).
The vegetation of most of these pingos was the same as the vegetation between them, indicating their seasonal nature. With years a part of the pingos has not changed either their sizes or the species composition. *Sphagnum* mosses form a solid cover where such species as *Sphagnum girgensohnii* Russ., *S. rubellum* Wils., *S. magellanicum* Brid. (= *Sphagnum medium* Limpr.) as well as a range of others are common. Apart from *Rubus chamaemorus* that dominates the grass-shrub layer, there are subdominating species *Carex rariflora* (Wahlenb.) Smith and *C. rotundata* Wahlenb. The height of *Ledum palustre* does not exceed 10-15 cm both on pingos and between them.

A part of migratory pingos gradually changed their appearance increasing in sizes that resulted in gradual drying-out firstly the pingo top, then the slopes (figure 4).
As a result, Sphagnum mosses were gradually replaced by lichens, which have replaced a part of vascular plant species as well, for example, plants of Carex. On small pingos, there are either still no lichens or their species diversity is very low counting 1 to 3 species (e.g. Cladonia arbuscula (Wallr.) Flot., C. rangiferina (L.) Weber ex F.H. Wigg., Cetraria laevigata Rass.) possessing a very wide ecological range with regard to habitat factors. The higher a pingo, the greater the diversity of lichens. Thus, a part of pingos both near and at a distance from the barrier beaches is almost fully occupied by epigeal fruticose lichens with dominating the Cladonia species among them: C. arbuscula, C. ciliata (Stirt.) Trass, C. tenuiformis Ahti, and C. rangiferina. Occasionally bare spots of soil without vegetation can be found on pingos, these gaps are partly covered by lichens with cup-shaped podetia (Cladonia chlorophaea (Flörke ex Sommerf.) Spreng., C. coccifera (L.) Willd., C. cryptoclorophoecae Asahina, C. pleurota (Flörke) Schaer.). The group of species of the Parmeliaceae family (Cetraria laevigata, Gowardia nigrescens, (Ach.) Halonen, Myllys, Velmala et Hyvärinen, Coelocauleon divergens (Ach.) R. Howe, Flavocetraria cucullata (Bellardi) Kärnefelt et A. Thell, F. nivalis (L.) Kärnefelt) also takes an active part in the formation of the lichen cover of pingos.

Among the Parmeliaceae family, Alectoria ochroleuca (Schrank) A. Massal. occurs less frequently and closer to drier areas of barrier beaches. The Sphaerophoraceae family is often represented by Sphaerothecophorus globosus (Huds.) Vain. Starting with the top of the pingo, lichens gradually spread onto the slopes and eventually fully covering them. This demonstrates that the pingos have completely been formed and have existed for several years. The study has also shown the lichen species heterogeneity on pingos. Some pingos are covered with prevailing Flavocetraria cucullata and seldom Cetraria laevigata, Cladonia rangiferina, Sphaerothecophorus globosus, on others Gowardia nigrescens, Coelocauleon divergens dominate. It has often been noticed that one side of the pingo is, for example, covered with Flavocetraria cucullata, Cetraria laevigata, Cladonia aminaurocraea (Flörke) Schaer, while the other side is occupied by only Cetraria laevigata. At the same time, there hasn’t been identified any strong correspondence between the growth of lichens on pingos and the slope exposure. Flavocetraria cucullata, F. nivalis, Cetraria laevigata, Gowardia nigrescens, Cladonia rangiferina, C. maxima (Asahina) Ahti, Sphaerothecophorus globosus can be found in low places among pingos. It can be noticed that on large pingos, especially near barrier beaches, lichens are gradually displaced by shrubs of different sizes.

4. Discussion
On the north-eastern coast of Sakhalin Island as well as in other regions both the formation and the growth of migratory pingos and the development of vegetation on them depends on many factors such as average yearly temperatures, the height of snow cover, moisture conditions, and others [1]. Thus, on the wetland tree vegetation is hardly presented despite there are some areas of sparse larch forests with dwarf cedar pine surrounding it. However, on the Chaivo spit individual specimens of Larix cajanderi Mayr and Pinus pumila can be found on some migratory pingos reaching a height of 50-60 cm and a length of 3-4 m, i.e. the conditions for the growth of trees and shrub are created. Therefore, pingos enable the formation of new environmental niches for plants and lichens. The monitoring of the changes of migratory pingos on the bogs of the Chaivo spit has allowed us to notice both the heaving of the pingos and their melting on little spots that confirms the cyclic nature of the bog transformation process in general [15]. Some of the typical vascular plant species indicating the presence of permafrost layers are C. rotundata and a range of Sphagnum species which complies with the view of F Oksanen [16].

The surveys of the vegetation on migratory pingos and between them allows to state that most of the small pingos on the bogs of the Chaivo spit are in two stages of development: embryonic and the stage of the young pingo, according to the matching of pingo and vegetation development stages [17, 18]. The vegetation on them is represented by the same hydrophilic species as in the surrounding bog. At the same time, the pingo vegetation gradually decreases in size. However, a part of the pingos has already transferred to the maturity stage, i.e. to drier (drained) conditions. It is indicated by the presence of such vascular plant species as Ledum palustre, Rubus chamaemorus, Rhodococcus vittis-idea.
The species composition of lichens also depends on the size of pingos. On young pingos, there is a small number of lichens growing (2-3 species) possessing a wide ecological range while on more developed and drier pingos their species diversity increases. Apart from the changes in the growing conditions (drying out) the increase in lichen species diversity is related to the lifetime of the pingo. Lichens are slowly growing organisms; therefore they need some time to occupy a new habitat. That may also be evidence that the largest pingos have existed for a long time.

5. Conclusion

Many years of surveys have shown that some pingos on the bogs of the Chaivo spit have increased in size where the process of displacement can be clearly seen (primarily the replacement of mosses by lichens which in turn are gradually displaced by herbaceous plants and small shrubs). These processes are particularly intensive on pingos located close to barrier beaches although they also take place on particular pingos located at a distance from barrier beaches. Numerous small pingos are observed moving away from the edge of the wetland. The vegetation on them is either entirely the same as between them (the embryonic stage and the young pingo development stage) or contains lichens (the mature pingo stage). On some small pingos an increase in the proportion of lichens in the total vegetation has been noted. Thus, the current vegetation status of the Chaivo spit’ bogs indicates the formation of both perennial and numerous annual (seasonal) pingos as a result of peat freezing. An increase in the proportion of perennial pingos covered by lichens was identified during the study period. The need for further studies of changes in bog vegetation in areas of cryogenic processes in northern Sakhalin is also reasoned by changes in climate conditions in general.

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