Urban Forestry & Urban Greening 11 (2012) 113–119

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.de/ufug

Characteristics of the urban forests in arctic and near-arctic cities

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ARTICLE INFO

Keywords:
Forest
Limitations
Tree selection
Urban

ABSTRACT

The urban forest of three arctic and near-arctic cities (Murmansk in Russia, Nuuk in Greenland, and Reykjavik in Iceland) were surveyed to determine tree species composition and structure. Interviews with local authorities were conducted to learn about the history of urban tree planting. The urban forests of all three cities were composed of a limited number of trees and tree species due to abiotic constraints of the arctic and near-arctic environment. These limitations include: low temperature, short growing season, high wind velocity and permafrost. A total of 28 species were observed in the three cities. Only three of these (*Alnus incana* (L.) Moench, *Picea abies* (L.) Karst., *Betula pubescens* Ehrh., and *Salix glauca* L.) were observed in all three of the cities. Planting designs that created windbreaks for pedestrians were common along streets in Murmansk and Reykjavik. Street trees have not yet been introduced in Nuuk, but trees were found in cemeteries, parks, and on private property. Older portions of cemeteries in all three cities were characterized by trees planted directly on graves. These grave trees were the first trees to be introduced in these cities. Subsequently, 'trial and error' was used by local residents to plant trees. Much of these plantings failed. In recent times arboreta were established near all three cities to identify species suited for planting under arctic and near-arctic conditions. Trees identified in these test gardens are now being planted in Murmansk and Reykjavik.

Introduction

The term 'Arctic' is used in relation to the northerly portion of the earth, usually those areas within the 'Arctic circle', or above latitude 66° 33′N latitude. This portion of the earth is characterized by a very cold winter climate, extremes in photoperiod, limited land mass, and small human populations. The word 'Arctic' comes from the Greek *arktikos*, meaning "near the bear" in reference to the constellation Ursa Major (the great bear) which is a prominent constellation in the far northern sky. Much of the arctic region is covered by water forming the Arctic Ocean. Land exists around the southern margins of this ocean primarily in parts of Norway, Sweden, Finland, Russia, the United States, Canada, Greenland, and Iceland. The non-glaciated and non-permanent snow field portions of the arctic landmass support either tundra or the northern portions of the boreal forest.

One finds in many arctic and near-arctic cities a continuing interest in the establishment of trees and the development of urban forests. The purpose of this paper is to report on research conducted to understand the establishment of urban forests within or near the Arctic Circle. It was anticipated that knowledge of the history of the establishment of urban forests in the arctic and near-arctic would be useful to other arctic and near-arctic cities interested in establishing and/or expanding urban forests. The approach used to select trees for planting in arctic and near-arctic cities may have applications to tree selection for cities located in other extreme environments.

Limitations of the arctic environment for tree growth and survival

Five factors limit tree growth and survival in the arctic and near-arctic: temperature, growing season length, wind, permafrost and biotic interactions.

Temperature

Arctic and near-arctic environments are characterized by low temperature. Cold winter temperatures for more northern locations in the Arctic average as low as −40 °C with record low temperatures of −69.8 °C recorded in Snag, Canada in 1892 and −68 °C in Oymyakon, Siberia in 1933 (Athropolis, 2005). The average summer high temperatures for more northern stations are below 0 °C. Table 1 compares the patterns of temperature for the three cities studied. Low winter temperatures also occur at continental stations south of the Arctic in North America, Europe and Asia (e.g., extreme low temperatures in Edmonton, Canada = −49 °C; Moscow, Russia = −42 °C; Irkutsk,

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doi:10.1016/j.ufug.2011.07.007

Table 1
Temperature and precipitation patterns for three arctic and near-arctic cities (adapted from Athropolis, 2005; Meteorologyclimate.com, 2010).

City	Average monthly temperature (°C)		Average maximum temperature (°C)		Average minimum temperature (°C)		Extreme low temperature (°C)
	January	July	January	July	January	July	
Murmansk	−11.1	12.8	−7.4	17.4	−14.0	8.8	−39.4
Nuuk	−8.3	7.2	−6.1	9.4	−10.6	4.4	−29.5
Reykjavik	−0.5	11.1	1.7	11.1	−2.8	8.3	−24.5

Russia = −50 °C). Trees have survived these low temperatures, thus low temperature alone is not limiting trees survival in the arctic.

Short growing season

The 19th century climatologist Wladimir Koppen identified the correspondence between the Arctic tree line and the 10 °C summer isotherm. He concluded that forest could not survive where the average temperature in the warmest calendar month of the year is below 10 °C. He used this 10 °C summer isotherm to separate the polar climate from the boreal climate in his climate classification (McKnight and Hess, 2000). Koppen's conclusion was based on limited climatic data and limited knowledge of the distribution of trees. More recent data and information on tree distribution suggest that the Arctic tree line is often south of the 10 °C summer isotherm (Athropolis, 2005).

The length of the growing season is a more important factor limiting tree growth and survival than low temperature in the arctic and near-arctic. Various studies of timberlines in Alpine settings have shown a significant correlation between of the length of the growing season to tree distribution (Marek, 1910; Daubenmire, 1954; Tranquillini, 1979). Along a south to north transect from Dawson to Sachs Harbor in north-western Canada a gradient of decreasing length of growing season is encountered (Table 2). Between Aklavik with its 90 day growing season and Tuktoyaktuk where the growing season is only 60 days a transition from boreal forest to tundra occurs.

Studies of tree growth along altitudinal gradients have shown significant correlations between height, leaf, and stem diameter growth and decreasing length of the growing season (Tranquillini, 1965; Tranquillini and Unterholzner, 1968; Ott, 1978; Jarvis and Linder, 2000). Radial stem growth is critical to the annual formation of vascular tissue in perennial plants. Radial stem growth occurs after shoot elongation and leaf growth and is dependent upon photosynthesis during the current year. Shortening of the growing season can be very detrimental to formation of xylem (Kozlowski and Pallardy, 1979).

Photoperiod has an important control over several physiological processes in trees and it is a factor in the short growing season in the arctic and near-arctic. Initiation and cessation of dormancy are closely related to changes in photoperiod that affect plant hormones. Heide (1974) demonstrated the interaction of photoperiod and temperature in the growth of ecotypes of *Picea abies* (L.) H. Karst. Northern ecotypes have adapted to the extremes in arctic and near-arctic photoperiods and this may be an important factor to consider in tree planting in arctic and near-arctic cities.

Table 2
Length of growing season in north-western Canada (Atlas of Canada, 1957).

Settlement	Latitude	Length of growing season (days)	Vegetation types
Dawson	64°N	130	Boreal forest
Aklavik	68°N	90	Boreal forest
Tuktoyaktuk	70°N	60	Tundra
Sachs Harbor	72°N	50	Tundra

Wind

High wind velocities in the arctic and near-arctic affect the normal growth form of trees and may cause trees to be blown over. Average annual wind velocities at 50 m above the ground in the three cities studied average 8.3 m/s (Murmansk = 7.5, Nuuk = 8.5, Reykjavik = 9.0). In contrast the similar readings for most of Europe, Asia, and North America within the temperate zone average only 4.0 m/s (Dellinger, 2008). High velocity Arctic winds can desiccate plant tissue resulting in mortality. The krummholtz growth form, where trees grow above the level of winter snowfall and are blasted by ice crystals driven by the wind across the snow, is often common on windy sites at the margins of the boreal forest (Kroner, 1999).

Permafrost

Conditions for tree growth in the arctic and near-arctic are exacerbated by permafrost. Frozen water beneath the soil surface limits the growth of roots. Soil layers above the permafrost often become saturated as melting occurs in the summer, and anoxic conditions develop which further limit tree growth. Refreezing of the upper layers of the permafrost in the winter can result in frost heave of tree seedlings and the tipping over of mature trees. Most areas of tundra are underlain by continuous permafrost. Boreal forests usually exist in areas of sporadic permafrost or no permafrost.

Biotic interactions

Herbivory, disease, symbiotic relationships, and the vectoring of reproductive propagules influence the growth and distribution of trees throughout the world's biomes. These biotic interactions no doubt have an influence on tree distribution in arctic and near-arctic environments but unfortunately have not been studied as extensively in these regions. Among these interactions, herbivory by reindeer/caribou (*Rangifer tarandus* L.) has been reported to affect the growth and distribution of shrub and tree willows in the tundra-forest ecotone (Manseau et al., 1996; den Herder and Niemelä, 2003; Eskelinen, 2008; Pajunen et al., 2008; Pajunen, 2009). Strathdee and Bale (1998) suggest that insect herbivory is not a significant factor in the distribution of trees in the arctic and near-arctic. Few insect herbivores exist in the region and in the case of psyllids (Homoptera), that feed on willow species, their distribution does not extend as far north as their host species (MacLean, 1983).

Tree mortality has dramatically increased in portions of the Canadian and Alaskan boreal forest in the last decade due to global warming (Whittwer, 2004; Carroll et al., 2006). Insect herbivory may play a more important role in the distribution of tree species in the arctic and near-arctic as global warming increases.

Tree species occurring in the tundra-forest ecotone form mycorrhizae with fungi as well as serve as hosts for fungal pathogens; however, studies of the significance of these interactions to the distribution of trees in the arctic and near-arctic could not be located. Tree seed dispersal by animals and insects is not common in the arctic and near-arctic. Of the 28 species reported in this study 82% are wind dispersed.