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Drought damage in the park forests of the city of Helsinki

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Abstract

During spring and summer 2003 severe drought-caused damage was observed in the park forests of the city of Helsinki; especially in barren site pine and spruce stands. The objectives of this study were to map and document the extent of the damage through the use of existing geographical information, digital aerial photography and field surveys and to examine the feasibility of assessing drought damage by visual interpretation of digital aerial photography. Our aim was also to assess the reasons for drought damage in Helsinki city park forests using geographic information system (GIS) analyses of existing interpretative and geographical data, i.e. digital aerial photographs, rainfall statistics and the compartmentwise GIS database of the park forest site and soil types.

The total amount of area falling into serious damage classes represented approximately 25 ha (the total forested area in Helsinki is about 3700 ha). A majority of these areas were located on rocky sites having low stem volumes. The total proportion of damaged stock volume was estimated as 17 300 m^3, which is 3.3% of the total stock volume in the study area. An accuracy assessment showed that visual interpretation of digital aerial photos is an excellent tool for assessing drought damage. The mean estimation error was 0.7 classes, and errors comprising $\leqslant 2$ classes were found in all test grids. The overall correct percentage of photointerpretation was 46%, and estimation was unbiased (kappa 0.264). The forest site and soil type together with the tree species on site showed the greatest correlation with drought damage. The drier and more barren the site, the more likely that damage will occur. Roadside forests were in better condition than areas located further off the roads. Hills clearly impacted the condition of the trees through soil type and flow.

Keywords: Drought damage; Forest inventory; Digital aerial photographs; Park forests; Visual interpretation; GIS analysis

1. Introduction

Detailed and timely information on forests is required e.g., for traditional forest management, forest certification and monitoring of forest health or biodiversity. This increased demand for information combined with the desire to reduce costs have resulted in a need to increase the efficiency of forest information acquisition. Technologies for acquiring spatial forest resource information have developed rapidly during recent years. Fieldwork has been enhanced by global satellite positioning systems (GPSs), automatic measuring devices, field computers and wireless data transfer. Modern remote sensing, in turn, provides cost-efficient spatial digital data that are both spatially and spectrally more accurate than before.

Visual interpretation of aerial photographs and numerical satellite image analyses of medium-resolution satellite images (e.g., Landsat Thematic Mapper) have shown a capacity for large area forest-mapping tasks, such as the estimation of stem volume (Nyyssönen et al., 1968; Poso, 1972; Poso et al., 1984, 1987; Sader et al., 1989; Tomppo, 1990; Tokola et al., 1996),

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discrimination of tree species (De Wulf et al., 1990), and detection of forest changes (e.g., Singh, 1989; Häme, 1991; Olsson, 1991; Varjo, 1997). The results, however, have seldom been satisfactory for small-area inventories or for operative forest planning.

Recent results suggest that the most suitable type of remotely sensed imagery for detailed forest inventory, such as forest-planning purposes, is currently digital aerial photos (Holopainen, 1998; Pitkänen, 2001; Pekkarinen 2002, 2004; Anttila, 2002a, b, 2005; Korpela, 2004), laser scanning (e.g., Naesset, 1997, 2004; Hyyppä and Hyyppä, 1999; Hyyppä and Inkinen, 1999; Maltamo et al., 2004), very-high-resolution (VHR) satellite images (e.g., Wulder et al., 2004) or combination of these imageries (e.g., Leckie et al., 2003).

The main advantages of digital aerial photos compared with medium-resolution (ground resolution 5–30 m) satellite images are their favourable spatial resolution, reasonable imaging costs and their long tradition of use in forest planning. In addition numerical aerial photos can be rectified to a desired coordinate system. The effects of terrain elevation can be considered with a digital elevation model. The result of such rectification, an orthophoto, is spatially almost as accurate as a common map; in addition the image is highly scalable. Digital orthophotos are currently used mostly as background images in forestry mapping and geographic information system (GIS) applications, e.g., for on-screen visual interpretation (Holopainen, 1998). Several satellite imaging systems currently provide VHR data that have a spatial resolution better than 5 m. VHR satellite imagery can be utilized e.g., in mapping applications, which to date have been carried out in Finland exclusively with aerial photos. In forestry, high-resolution satellite imagery could in principle be used for forest-planning purposes, however the high cost of these images to date has hindered such development.

Urban environments are subject to environmental stress. As a result of outdoor activities and recreation those areas nearest housing districts show the greatest amounts of soil erosion and damage to the roots of trees (e.g., Lehvävirta and Rita, 2002; Lehvävirta et al., 2004). Additionally, the effects of traffic and air pollutants on trees are most intense in urban environments (e.g., Yang et al., 2004).

Remote-sensing imagery detects tree damage by monitoring changes in colour that are indicative of vegetation stress. Stress can occur when a plant is exposed to a number of environmental factors, including air pollution, acid rain, heavy-metal contamination of the soil, insect infestation and disease. The effect of stress is apparent in several wavelength areas, most notable of which is a shift in the position of the red edge toward the blue end of the spectrum and a decrease in the reflection of infrared wavelengths (Murtha, 1978; Reid, 1987; Franklin, 2001).

Colour-infrared (CIR) photographs have been widely used to detect various tree stresses. Heller (1978) showed that impacts of vegetation stresses can be detected using near-infrared wavelengths, remarkably before they can be seen at optical wavelengths. Different types of structural change in vegetation can either increase or decrease reflection in the near-infrared wavelengths (Murtha, 1978; Horler et al., 1983; Essery and Morse, 1992; Campbell, 1996). Murtha (1985) studied interpretation of insect damage using analogical CIR photographs. Damage was detectable in aerial photographs at scales of 1:2000 or larger. When 1:500 photographs were used, it was possible to detect individual damaged branches. Damage inventory could be performed at only one-fifth the cost of traditional field measurements.

The use of supervised classification of digital aerial photographs in detection of trees that were stressed by root injury was studied by Reich and Price (1998). The correct percentage of individual trees when 4 damage classes were used was about 50%. The density of the forest remarkably affected the accuracy of interpretation. Numerical interpretation produced better results than visual interpretation (Reich and Price, 1998).

Summer 2002 was one of the warmest in 100 years in the Helsinki area. The mean temperature was 18.3 °C, which is about 3 °C above the mean for 1971–2000. The summer was also extremely dry, since the rainfall in 2002 was only 399 mm; in comparison the mean rainfall for 1971–2000 was 642 mm. The groundwater level was the same as during the very dry season in 1941–1942. Summer 2003 was also hot and dry in the Helsinki area. The groundwater level increased in autumn 2003 and winter 2003–2004, remaining at normal levels during the rainy summer in 2004.

During spring and summer 2003, severe drought-caused damage was observed in the park forests of the city of Helsinki, especially in barren site pine and spruce stands. The City of Helsinki Park and Garden Department commissioned the University of Helsinki Department of Forest Management to assess damage with an inventory carried out in autumn 2003. The primary objective of this study was to map and document the extent of the damage, using existing geographical information, digital aerial photography and field surveys. A secondary objective was to examine the feasibility of assessing drought damage through visual interpretation of digital aerial photography. In addition, the reasons for drought damage in Helsinki city park forests were assessed by means of GIS analyses of existing interpretative and geographical data, i.e. digital aerial photographs, rainfall statistics and the compartmentwise GIS database of the park forest site and soil types.