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# The fragmented nature of tundra landscape

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ABSTRACT

The vegetation and land cover structure of tundra areas is fragmented when compared to other biomes. Thus, satellite images of high resolution are required for producing land cover classifications, in order to reveal the actual distribution of land cover types across these large and remote areas. We produced and compared different land cover classifications using three satellite images (QuickBird, Aster and Landsat TM5) with different pixel sizes (2.4 m, 15 m and 30 m pixel size, respectively). The study area, in north-eastern European Russia, was visited in July 2007 to obtain ground reference data. The QuickBird image was classified using supervised segmentation techniques, while the Aster and Landsat TM5 images were classified using a pixel-based supervised classification method. The QuickBird classification showed the highest accuracy when tested against field data, while the Aster image was generally more problematic to classify than the Landsat TM5 image. Use of smaller pixel sized images distinguished much greater levels of landscape fragmentation. The overall mean patch sizes in the QuickBird, Aster, and Landsat TM5-classifications were 871 $m^2$, 2141 $m^2$ and 7433 $m^2$, respectively. In the QuickBird classification, the mean patch size of all the tundra and peatland vegetation classes was smaller than one pixel of the Landsat TM5 image. Water bodies and fens in particular occur in the landscape in small or elongated patches, and thus cannot be realistically classified from larger pixel sized images. Land cover patterns vary considerably at such a fine-scale, so that a lot of information is lost if only medium resolution satellite images are used. It is crucial to know the amount and spatial distribution of different vegetation types in arctic landscapes, as carbon dynamics and other climate related physical, geological and biological processes are known to vary greatly between vegetation types.



## 1. Introduction

In order to understand the functions and dynamics of ecosystems, accurate knowledge about the relative proportions of various kinds of vegetation and other land cover types is important, and also details of their spatial distribution should be known. To date, a vast number of studies have been conducted to characterize forested ecosystems using various remote sensing based data and analysis methods, but much less studies have been conducted on Arctic ecosystems. Arctic areas are vast and difficult to access, and consequently only remote sensing aided methods offer possibilities of detailed mapping of larger areas (Laidler and Treitz, 2003).

Carbon dynamics and other climate related physical, geological and biological processes, known to be sensitive to climatic variation, have been found to vary greatly between vegetation types in the Arctic (Heikkinen et al., 2004; Schneider et al., 2009; Marushchak et al., 2013). Climate change has been predicted to be faster and more extensive in arctic areas than in other regions, with some changes predicted to accelerate warming even further through positive feedback mechanisms (ACIA, 2005). There is therefore an urgent need for realistic and accurate land cover classifications of arctic ecosystems.

Tundra ecosystems consist of a mosaic of different vegetation and other land cover types, which are distributed in the landscape in a very fragmented manner (Stow et al., 2004). This patchiness is a consequence of several factors related to the harsh arctic climate. The sparse vegetation cover is prone to such physical factors as wind and snow erosion which, in combination with seasonal and longer term changes in permafrost conditions, impact soil properties and cause small scale variation in vegetation and land cover.

Arctic areas are included in global and continental land cover datasets (Hansen et al., 2000; Bartalev et al., 2003; Heiskanen, 2008), but they are typically produced at such a coarse resolution that they cannot reveal actual vegetation patterns needed in global change studies (Heiskanen, 2008; Giri et al., 2013). Previously different Landsat satellite images (pixel size 30 m) have commonly been used in regional studies (Stow et al., 2004; Virtanen et al., 2004; Schneider et al., 2009), while MODIS or SPOT-Vegetation (pixel size 250 m–1 km) have been used in continental and global studies (Hansen et al., 2000; Bartalev et al., 2003). During recent

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years, several satellite image sensors with increasing spatial resolution have been launched (e.g. Ikonos, QuickBird, WorldView, GeoEye1-2). In some cases spectral resolution has also been improved, for instance GeoEye-2 has eight channels, facilitating the application of more detailed classifications.

Satellite image analysis and classification methods have also improved considerably. For example, new classification algorithms and signature analysis tools, as well as object-based, multiscale segmentation techniques, that take both spectral and spatial characteristics into account, have been developed. Object-based classification in particular gives new possibilities for high-resolution image analysis when compared to traditional pixel based techniques (see, for example, Wuest and Zhang, 2009). High resolution satellite images, in combination with improved computing technology and new analytical methods, enable the production of more accurate land cover classifications than were previously possible. Comparisons of classifications produced using the new versus the traditional techniques enables the evaluation of resolution dependent differences in the appearance of the landscape structure. Such comparisons can also aid our understanding of the implications of the information that is lost when coarser resolutions are used.

Land cover classifications should represent meaningful functional entities if they are to be a useful tool for researchers studying and modelling ecological and biogeochemical processes. The reliable determination of peatlands and tundra areas with mineral soil is, for example, essential for carbon stock and flux studies (Marushchak et al., 2013). In most of the existing classifications of tundra areas, peatlands are not separated with relevant functional subclasses, and in many cases peatlands are not distinguished from non-paludified areas at all. In this study, we have therefore focused on the distinction of different kinds of peatlands.

The overall aim of this study is to quantitatively evaluate differences in the landscape pattern of a tundra area, as it appears in land cover classifications of different resolution satellite images. We also test the accuracy and compare landscape metrics between land cover classes and different classifications. The purpose of this is to better understand the actual small-scale variation in land cover and how the classification resolution affects the representation of landscape structure. Our study thus highlights the importance of selecting an appropriate resolution of land cover mapping and classification when conducting environmental studies in arctic ecosystems.

## 2. Material and methods

### 2.1. Study area

The study area is a quadrat of 20 × 20 km located on the Rogovaya River, on the border between Nenets Autonomous Okrug and the Komi Republic in Northeast European Russia, approximately 100 km west of the Ural Mountains (Fig. 1). All bar graphs and table values are calculated only from the areas covered by two QuickBird scenes, hence all the comparisons are based on the same geographical location. This lowland area within the Usa River basin lies north of the forest line, though smaller forest patches, as well as scattered trees, can be found, especially along the river. Siberian spruce (*Picea obovata* Ledeb.) forms the coniferous tree line in this area but also some birches (*Betula pubescens* Ehrh. subsp. *czerepanovii* (N. I. Orlova) Hämet-Ahti) occur. The landscape is flat with the largest topographical variation being caused by the river valleys of the Rogovaya River, and smaller rivers and streams. The mean elevation of the area is 85 m, the lowest points are 60 m and the highest 120 m above sea level. About 80% of the area is between 75 and 95 m. Willows, varying from a few metres high treelike growth forms to bushes of only a few decimetres, grow in the river valleys and paludified depressions. This landscape, characterized by discontinuous permafrost, contains large mosaic peatlands with thermokarst fens and lakes, as well as raised permafrost peat plateaus, and also areas of drier tundra heaths on mineral soils.

### 2.2. Satellite images and programmes

Satellite images of three spatial resolutions were used to classify land cover and analyse landscape structure. The fragmentation as it appeared according to a classification of two (66 $km^2$ and 68 $km^2$) fine resolution QuickBird images (QuickBird© 2007, DigitalGlobe; Distributed by Eurimage/Pöyry) with a pixel size of 2.4 m (four channels), was compared to the results acquired using satellite images of medium spatial resolution. The satellite images of medium spatial resolution were a Landsat Thematic Mapper 5 satellite image, with a pixel size of 30 m, and an Aster (Advanced Spaceborn Thermal Emission and Reflection Radiometer) image with a pixel size of 15 m. The QuickBird and Landsat TM5 images were taken on subsequent days of the same year (4th and 3rd of July 2007, respectively), while the Aster image was taken 6 years earlier and 1 month later during the growing season (11th of August 2001), as no cloud free images could be found from the area taken in July during recent years.

Geo-referenced and geo-rectified QuickBird images were acquired, but they were geo-referenced still more accurately using *in situ* measured GPS data. The other images were geo-referenced to match the QuickBird images. Geo-referencing and pixel based classifications were performed using Erdas Imagine 9.3, while GIS analyses were conducted using several tools in ArcGIS 9.3 and ArcView 3.2. The classification of the QuickBird image was done through segmentation techniques using eCognition (Definiens Professional 5.0).

### 2.3. Fieldwork

The fieldwork was carried out during 6th–18th July, 2007. Two data sets were collected: 88 randomly distributed ground truth points with a minimum distance of 200 m between the points, and four transect lines. Random points were selected from a large random point dataset generated prior to going to the field. The transect lines were selected based on a false colour Landsat TM5 image to cover the widest possible variety of vegetation types. They were 900 m long and consisted of ten points at hundred metre intervals, from which vegetation biomass, soil properties and carbon stocks were also estimated. Each of these ten transect points consisted of three sub-points; one straight along the transect and the other two 15 ms to the sides, which means that a total of 120 transect points were investigated. At all these points (randomly selected as well as those along the transects) the vegetation types within a radius of 7.5 m were described and a photo was taken for later reference. The coverage of eight functional groups of plants, distinguished on the basis of their growth form (trees, willows and other bushes, dwarf birch, dwarf shrubs, forbs, graminoids, mosses, lichens) was estimated within this same area. In addition, the transition between vegetation types was described along the transect-lines where precise locations of changes in vegetation types were marked using a handheld GPS (Garmin Etrex Vista HCx), accuracy in open tundra generally 3–5 m.

### 2.4. Vegetation and other land cover classes

The landscape was classified into eight main land cover classes, of which six were vegetation classes. These were forest, willow, dwarf birch tundra, tundra heath, bog and fen. The two remaining non-vegetated classes were bare ground and water. A more detailed land cover classification was also created, in which the main land