9

Main Ecosystem Characteristics and Distribution of Wetlands in Boreal and Alpine Landscapes in Northern Sweden Under Climate Change

J. Jeglum, S. Sandring, P. Christensen, A. Glimskär,
A. Allard, L. Nilsson and J. Svensson
Swedish University of Agricultural Sciences
Sweden

1. Introduction

Wetlands and peatlands are integral parts of many of the world's biomes, forming important transition zones between upland and aquatic systems. These habitats have a high degree of complexity of hydrology, edaphic conditions, and vegetation composition, contributing to the biodiversity of landscapes and species richness. They act to influence and modify the movement of runoff and groundwater from uplands into streams and lakes, by laying down organic remains (peats), and absorbing and releasing elements, compounds, gases, and particulate and dissolved organic matter. They therefore act as hydrological water retainers and biological filters in the landscape.

Many kinds of wetlands and peatlands can be found, each with a particular hydrology and surface form, moisture and chemical regime, and range of vegetation types and associated biota. Owing to their hydrological characteristics, predominantly peat soils and hydrophytic plants, wetlands and peatlands are key habitats to indicate climate change, particularly changes towards drying (e.g., decreased precipitation, increased runoff from melting glaciers and snow pack). Changes in moisture regime will effect changes in the processes of peat accumulation and decomposition, release of nutrients and dissolved organic matter, and vegetation and species. Drainage for agriculture and forestry, peat harvesting, and development have already caused considerable areas of peatlands to decrease in depth and area. Owing to drying, some peatlands adjacent to uplands have decreased in depth to less than 30 cm, the defined depth for peatlands in Sweden, and thus the total area of peatland has decreased.

Drying also has caused changes in vegetation, for examples, advances of trees and shrubs from the margins into the centres of peatlands (e.g., Fig. 1; cf. Hebda et al., 2000; Linderholm & Leine, 2004), and the dying of Sphagnum by lowered water levels and being covered over by leaf litter. Hebda *et al.* estimated the zone of influence of water lowering in Burns Bog, a bog on the Fraser River Delta in southern British Columbia, Canada, to extend over 100 m from a peripheral ditch. The Swedish Wetland Inventory, VMI, (Gunnarsson & Löfroth, 2009) was conducted during 25 years and generated results that indicate that about 15% of mires in the northern part of Sweden are strongly influenced or even destroyed, and 55% are weakly influenced while the rest are considered uninfluenced by human impact. Impacts are mainly from machines used for forestry and the digging of ditches. Small mires and mires in the Scandinavian Mountain Range were not covered by the VMI, however, and it may be assumed that processes such as increased tree cover or successional shifts to other vegetation types are more evident in such habitats. The main threats to the mountainous mires are tracks from all-terrain vehicles and snowmobiles, and much concern has been expressed from County Boards and the Swedish Environmental Protection Agency about this issue (e.g. Renman, 1989; Allard et al., 2004).

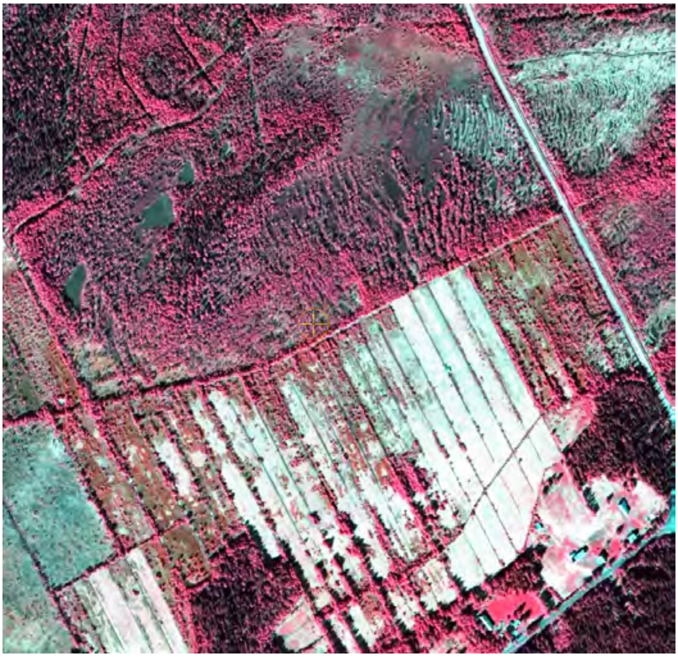


Fig. 1. A significant proportion of the arable land in Sweden has been created through drainage of wetlands. The figure (Color Infra Red aerial photo) shows an area in southern Sweden. The farm buildings are placed on the uplands in the SE corner and the wetlands have been drained and form long rectangular arable fields (light tones). Trees and shrubs (pink tones) now invade along the ditches and into the center of some fields as a result of decreasing land use intensity. The area above the drained fields shows invasion of trees and shrubs on a previously open string flark fen.

It is generally anticipated that climate change will cause considerable impacts and changes on landscapes and ecosystems. Dale et al. (2001) provide a review of the impacts of climate change on forests, which included altering the frequency, intensity, duration, and timing of fire; drought; introduced species; insect and pathogen outbreaks; hurricanes, windstorms, ice storms; and landslides. Similar impacts may be expected in peatlands. Several reviews on predicted impacts of climate change on wetlands and peatlands have been published (Gorham, 1991; 1995; Gorham et al., 2001; Strack et al., 2004; Tarnocai, 2006; Warner &

Asada, 2006; Strack, 2008). European climate models predict increases in warm indices and decreases in cold indices (Persson et al., 2007; Lind & Kjellström, 2008). Higher summer temperatures will promote higher evapotranspiration in the summer, resulting in deeper water tables in the wetlands. Relatively higher warming is expected for the interior in northern Sweden. On the other hand, there are predicted to be increases in wet indices in the north and dry indices in the south, and this may lessen the impacts of drying on wetlands in the north, and accentuate impacts of drying on wetlands in the south. Trends and trajectories are largely unknown, however, as are the influences on natural conditions and biodiversity.

The National Inventory of Landscapes in Sweden (NILS) has undertaken to monitor landscape changes owing to natural and anthropogenic disturbances, and ecological processes at the landscape scale (Svensson et al., 2009; Ståhl et al., 2011). NILS encompasses all terrestrial habitats in Sweden, and includes mapping of peatland and wetland types and characterizing the tree, shrub, field and ground vegetation, and surfaces. One of the main incentives behind NILS is to capture relevant data and provide analyses to answer the national Environmental Quality Objectives, of which the “Thriving wetlands” objective concerns the conservation and restoration of peatlands (e.g. Government of Sweden, 2009).

The aims of this chapter are to elucidate multiple-scale biodiversity aspects – i.e. landscape, community-ecosystem, population-species (Noss, 1990) – through area and distribution of wetlands and peatlands in northern Sweden; area and distribution of the Hydrotopographic types; and associated vegetation strata and ground conditions associated with the Hydrotopographic types. We include a discussion of the value of the NILS monitoring of the wetlands for assessing climate changes and other changes owing to anthropogenic causes in the context of biodiversity on multiple scales.

2. Study area

The study area is situated in the northern part of Sweden, coinciding with the two northernmost counties of Västerbotten and Norrbotten (Fig. 3). The landscape ranges from the coastal boreal areas consisting of often flat forested areas, up through the interior with a mixture of boreal forest and mires, to the mountains and birch-forested valleys of the Scandes Mountains. The study area has been classified into Natural Geographic Regions, sometimes referred to as Biogeographical Regions, according to the Nordic Council of Ministers (1977), Helmfrid (1996), and Lennartsson & Stighäll (2005). These regions were chosen as they take into account both east-west and north-south variations. As we wanted to study the distribution in the context of occurrences at different elevations as well as the climatic aspect, the regions were regrouped into five Elevation Zones which then were used as the basis for summarizing wetland and peatland data (Fig. 2).

2.1 Characteristics of the elevation zones

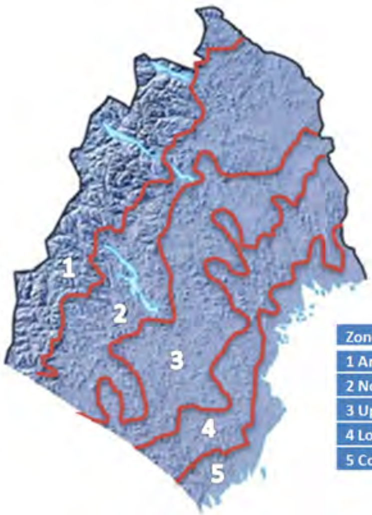
Zone 1. The Arctic/Alpine zone has steep mountains with glaciers and vegetation zones at lower altitudes. The prevailing Atlantic wind and precipitation provide strong climatic differences between westward slopes and eastward facing slopes with more continental climates. Nutrients in the bedrock and soil are varied and the soil layers are usually very thin. The zone encompasses the gradual shift from forest to treeless alpine habitats, and, hence, the alpine tree line.

Zone 2. The Northern boreal zone has wide heaths and forests of mountain birch or coniferous trees, mainly Norway Spruce (*Picea abies*) but also Scots Pine (*Pinus sylvestris*), mixed with mires. The relief includes scattered mountains and plateaus.

Zone 3. The Upper middle boreal zone has mixed coniferous forests in flat or hilly terrain and is rich in mires of mixed types, together with willow and birch swamps. The zone is predominantly above the highest post-glacial coastline and the metamorphic bedrocks are covered by till. Few and scattered human settlements of late date can be found.

Zone 4. The Lower middle boreal zone is vegetated by coniferous forest and swamp forest, in a hilly terrain rich in lakes. The transition from above to below the highest post-glacial coastline occurs predominantly in this zone.

Zone 5. The Coastal boreal zone is characterised by sandy or morainal islands and coastal boreal plains, with hilly terrain and valleys dominated by marine sediments back from the coast. The vegetation ranges from the marshlands, meadows and lowland forests along the Gulf of Bothnia coast to the inhabited parts where cultivated land and towns are situated (sparsely), which brings open grassland and deciduous forest between the coniferous parts. The precipitation is somewhat higher than the inland forest zones.



Zone	Mean height	Min height	Max height	Mean STD
1 Arctic/Alpine	743	352	1352	40
2 Northern boreal	495	252	712	14
3 Upper middle boreal	364	225	568	13
4 Lower middle boreal	168	65	275	12
5 Coastal boreal	49	1	173	7

Fig. 2. The five Elevation Zones from west to east: 1 Arctic/Alpine, 2 Northern boreal, 3 Upper middle boreal, 4 Lower middle boreal, and 5 Coastal boreal zone. The zones are based on the Natural Geographic Regions of Sweden (Helmfrid, 1996). The table in the figure shows the mean, minimum and maximum of elevation heights (m above sea level), and the standard deviation of the mean height.

3. Methods

The data are collected from the NILS programme which uses a strategically and systematically placed gridwork of 5×5 km squares (Ståhl et al., 2011). There are in total 631 squares and a full rotation of the inventory consists of 5 years. Two types of inventory are undertaken within a central, 1×1 km square, i) inventory by aerial photo interpretation in stereo models and ii) field-based inventory of sample plots and sample transects. This chapter will deal only with the aerial photo part of the inventory. The data set consists of the first set of air photo samples collected in 2003 to 2005, and is restricted to the northern part of the country. The data used here consists of 116, 1×1 km squares, which contain a total of 3229 registered polygons interpreted from the Colour Infra-Red imagery (Fig. 3).

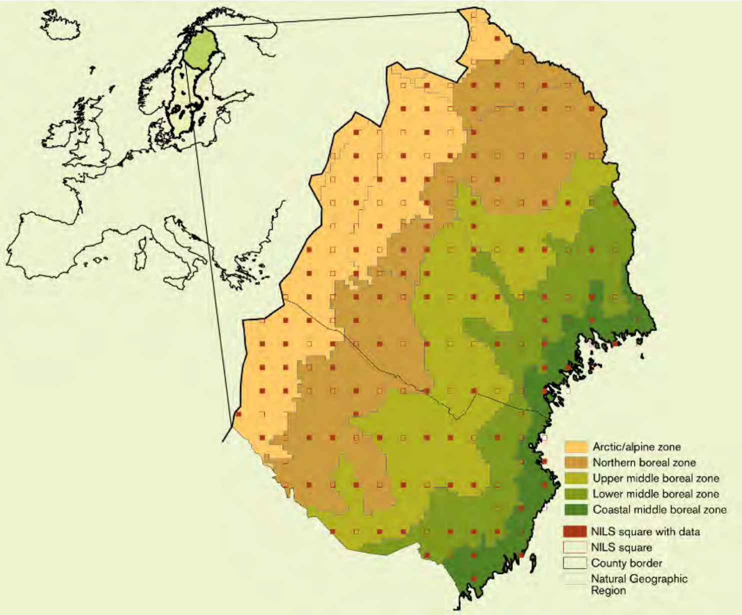


Fig. 3. The study area with five Elevation Zones, and with the distribution of the 1x1 km squares. The grid locations of the permanent NILS squares are indicated in red, the yet unsampled squares are not filled.

3.1 Aerial photo interpretation

The scale of aerial photos allows mapping based on vegetation structure and overall vegetation composition (e.g. Ihse, 2007; Morgan et al., 2010). A basic level of classification utilizes the fundamental division into bog (rain-nourished) or fen (mineral soil nourished). Each of the finer divisions is based on different hydrotopographic conditions – slope (e.g., flat, sloping, raised), location in landscape, and distinctive vegetation patterning on the surface. At the polygon level the types are described for general dominance of main vegetation in the understory. Within polygons smaller units, such as hummocks, hollows, and flarks, can be identified. This means that one can use the structure of the vegetation and peat surface, along with several other ecological indications, to distinguish between the different main types of mires and vegetation elements inside them. On the landscape scale the different hydrotopographic types of mires can be put together as mire complexes (Rydin et al., 1999). We hypothesize that the geographic distributions and areal extents of types will vary from east to west and north to south in northern Sweden, and also when comparing north with south Sweden.

The interpretation methods are described in detail in Allard et al. (2003, 2010). Strict rules are applied for spatial mapping accuracy and timing during the vegetation season. The technology is based on viewing the digital images in stereo in a computer-based photogrammetric system, with ancillary data such as maps and geology in a geographic information system (GIS program). The NILS program uses quantitative and qualitative variables in a context-dependent variable flow, instead of the usual predefined classes. This allows for aggregation of variables in several different ways, making several different classifications possible, after the data is registered into a geographical database. Similar basic variables are used both for the aerial photo interpretation and for the field survey, although the entire square is inventoried in the aerial photos, and sample plots and line inventories are registered in the field. A decision tree was used to define criteria for the polygon delineation in the aerial photo inventory, with a smallest mapping unit of 0.10 ha (31.6×31.6 m). When this study was made, complete data from the interpretation was available for the years 2003, 2004 and 2005 of the first rotation in NILS.

3.1.1 Variables in NILS relevant to mires

The NILS program operates on variables, in total 356 of which 156 are documented in the aerial photo interpretation. The main variables documented in wetlands and peatlands come from the recognition of the division between fen and bog; the recent emphasis in peatland classification on physiography, morphology, and hydrotopography; and vegetation elements (e.g., National Wetlands Working Group, 1988; Löfroth, 1991; Gunnarsson & Löfroth, 2009).

There are 17 Hydrotopographic mire types recognized for Swedish conditions (Gunnarsson & Löfroth, 2009). In this study, the mires were the primary focus, but we added a 'Non-mire wetland' type by using the category of semiaquatic land (occasionally flooded by fresh, brackish or salt water). Swamp forests are not included as one of the Hydrotopographic mire types, although they are registered in the aerial photo interpretation. The Hydrotopographic mire types are registered in the aerial photo interpretation of polygons as uniform hydrotropographic units, and can be classified together as large-scale mire complexes.

Thirteen Field and bottom layer vegetation types are recognized. Only one type of field and bottom layer type is registered as the dominant class for each polygon, since several types may occur in one polygon. Seven elements in a Microtopographic series are registered as percentages inside each polygon. The Microtopographic elements are defined on physiognomic as well as vegetation composition aspects of the field and bottom layer, ground level, and firmness of the substrate, following the Microtopographic series tradition in Swedish mire ecology (Rydin & Jeglum, 2006).

3.1.2 Influences and disturbances

Disturbance descriptors are important when explaining the kind of vegetation and ground cover. In the NILS program they are registered for example as peat harvesting, ongoing or historical, and influences including such disturbances as vehicle tracks, ditching, dredging, and mechanical site preparation. Other facts that can be derived from the data are forestry impacts, mowing, agriculture, erosion by wind or water, and burning. Of particular interest for climate change is the designation of productive forest land, fjell and tree line, and tree-limiting climatic impediments below the tree line.

3.1.3 Tree and shrub cover

The variables dealing with tree and shrub cover are important indicators of community-ecosystem and population-species biodiversity, land influences, disturbances, and climate change. These variables are important to identify those polygons that have had some influence by forestry, for example, tree planting being indicated by the patterns of tree distribution. In the aerial photo inventory, the distinction between trees and shrubs/small trees are as follows: all woody vegetation above 3 m height and in mountain birch forest above 2 m height are considered trees, regardless of species, and all woody vegetation below these heights falls into the shrub/small tree variable.

Variables in NILS relevant to mires

Hydrotopographic Mire Type

Fen
- Flat or slightly sloping fen
- Limnogenous fen
- Sloping fen
- Hill fen
- String flark fen
- Fen, strongly influenced

Bog
- Plateau bog
- Domed bog
- Sloping bog
- Flat or weakly raised bog
- Net bog
- Blanket bog
- Bog strongly disturbed

Mixed mire
- String mixed mire
- Mosaic mixed mire
- Palsa mire
- Mire, weakly raised bog or fen

Microtopographic Series
- Hummock (Dwarf shrub dominated)
- Lawn
- Carpet
- Mud-bottom
- Flark pools
- Bog pools
- Marsh fen, Shore fen

Field / Bottom Layer
- Field cover/bottom layer missing
- Graminoid- or herb-dominated
- Graminoid-dwarf shrub type
- Dwarf shrub dominated
- Lichen-dwarf shrub type
- Lichen type
- Belt formation of e.g. *Phragmites* spp.
- Tall sedge
- Low sedge
- Sphagnum dominated
- Other moss dominated
- Logging residues
- Field layer/Ground layer in shadow

Trees and Shrubs
- Tree cover in 4 types
- Tree height
- The pattern of tree distribution in 8 subclasses
- Tree species mixture in 6 subclasses
- Height dispersal in 4 subclasses
- Occurrence of broadly crowned trees, in percentage
- Occurrence of shrubs in 4 subclasses
- Shrub cover, deciduous and needle-leaved.
- The pattern of shrub distribution in 8 subclasses

4. Wetland area and distribution

The main factors of peatland formation are climate, relief (topography), parent material, biota, and time. The key factor is relief, with flatness or concavity being the most important types of relief. Within the climate regime, the two climatic factors temperature and moisture (humidity) are interrelated in terms of control on wetland and peatland biota and community development.

The total number of wetland polygons in 116 sampled squares was 3229, and the average number of polygons per square was 28.9 (SE 2.1, median 25, minimum 1, maximum 105). Across the Elevation Zones the highest numbers of squares were 34 in the Arctic/Alpine zone, and 32 in the Northern boreal zone, decreasing to 23 in the Upper middle boreal zone, 14 in Lower middle boreal, and 13 in the Coastal boreal zone (Table 1). The higher numbers in the Arctic/Alpine, Northern boreal, and Upper middle boreal are because of the NILS sampling strategy to establish a denser gridwork of squares in the Alpine and adjacent interior land where landscape data are redundant or missing (Ståhl et al., 2011).

Calculation procedure for determining wetland areas for zones:

1. for each stratum*, divide the total wetland area per inventoried 1×1 per km square in the zone by the number of squares sampled to get '*mean wetland cover / square*';
2. multiply by 25 to get 'wetland cover / 5×5 per km square'
3. multiply by the total number of squares from which the sample was taken in the stratum to get '*estimate of the total wetland area per stratum*'
4. for each zone, calculate the sum all strata areas to get '*estimate of the total wetland area per zone*'
5. obtain the '*estimate of the total terrestrial area per zone*' by doing step 1 to 4 for terrestrial land cover instead of wetland cover.
6. obtain the *'wetland proportion'* by dividing the estimated total wetland area (from step 4) by the estimated total terrestrial area (from step 5);
7. multiply the wetland proportion by the corresponding terrestrial area of the zone to obtain '*ratio estimate of total wetland area*'.

* The distribution of sample squares follows a stratified design with least sampling effort in the central boreal parts of Sweden (Fig. 3; Ståhl et al. 2011). Stratum borders do not coincide with zone borders.

4.1 Wetland areas in squares and zones

The total wetland areas compared amongst Elevation Zones were significantly different (One-way ANOVA, $F = 4.76$ and $P = 0.001$; Fig. 4). The Northern and Upper middle boreal zones achieved the highest total wetland areas, and the Coastal boreal zone the lowest. The minimum cover achieved among squares was 1180 m^2 in the Coastal boreal zone; the maximum was 898163 m^2 in the Upper middle boreal zone, which is close to filling a full 1×1-km^2 square (1 million m^2). Expressed as percentages of the 1×1 km^2 square (10^6 m^2) these are 0.12 and 89.8%, respectively.

Total wetland area depends on the areal sizes of the elevation zones, which are not equal. To obtain a truer picture of the relative area covered by wetlands, we calculated the relative percentages of land covered by wetland in each zone (Table 1). The highest percentages of wetlands are in the Upper middle boreal zone followed closely by the Northern boreal zone. The Arctic/Alpine and the Coastal boreal zones have the lowest percentages, with a slightly higher value in the Lower middle boreal zone. The percentage cover of wetlands in the whole study area was 20.56% (SE 1.87). This matches well with other estimates of about 20% for Swedish wetlands (Hånell, 1989; Joosten & Clarke, 2002; Paavilainen & Päivänen, 1995; Christensen et al., 2007; Gunnarsson & Löfroth, 2009). However, all these references refer to the whole of Sweden, whereas the present paper deals only with Northern Sweden. A summary of wetlands comparable to the present one could be done for all southern Sweden below the study area.

Elevation zone	Sample size (Number of squares)	Total terrestrial land area (km^2)*	Estimated percentage wetland of terrestrial area, with standard errors		Relative standard error
1 Arctic/Alpine	34	33905	12.39	(2.42)	0.20
2 Northern boreal	32	45084	25.86	(3.57)	0.14
3 Upper middle boreal	23	37769	26.54	(4.10)	0.15
4 Lower middle boreal	14	23860	16.35	(6.02)	0.37
5 Coastal boreal	13	12127	14.36	(3.51)	0.24
Total	116	152747	20.56	(1.87)	0.09

* Terrestrial land area (excluding water) obtained from the Swedish road map series (GSD-Vägkartan, vektor, 1:100 000, Swedish Land Survey)

Table 1. Wetland statistics in the 116 1×1-km^2 squares. Estimated wetland area as a proportion of the terrestrial land area.

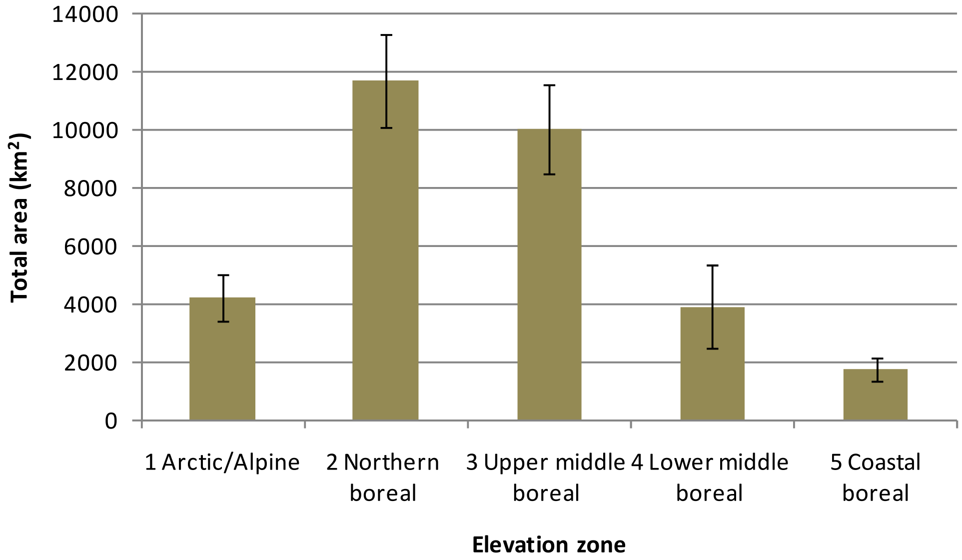


Fig. 4. Estimated total areas of wetlands in the five Elevation zones: Arctic/Alpine, Northern boreal, Upper middle boreal, Lower middle boreal, and Coastal boreal. Error bars indicate standard errors.

4.1.1 Variation and adequacy of sample

There was high variation among squares owing in part to the variation of wetlands within the zones, and also to the variation in numbers of squares amongst the zones. Relative standard error (Standard error divided by the estimate) indicates the quality of the estimate and the adequacy of sample (Table 1).

The lowest numbers for relative standard error for the wetland area estimate were obtained for the Northern and Upper middle boreal zones, indicating an adequate sample size of 32 and 23, respectively. The other zones had higher relative standard errors for estimated wetland areas indicating that the numbers of required squares for adequacy exceeded the actual numbers of squares sampled. However, for all 116 squares combined, the relative standard error was below 15%. In other words, for sampling the whole study area the sample was adequate, but for the five individual zones, only the two zones with the highest wetland covers were adequately sampled.

4.2 Sizes of wetland polygons

Mean number of wetland polygons varied amongst squares and zones (Table 2). The occurrence of wetland polygons was highest in the Upper middle and Northern boreal zones, with 39.6 and 31.5 polygons per km^2, respectively. The other three zones had similar number of polygons per km^2. The mean areas of individual polygons were largest in the Arctic/Alpine zone and decreased progressively towards the Coastal boreal zone. However, mean polygon size among zones was not significantly different, (ANOVA, $F = 0.76$ and $P = 0.552$; Table 2). The smallest wetland polygon was 331 m^2, sampled in the Coastal boreal zone. The largest wetland polygon was 428620 m^2 sampled in the Arctic/Alpine zone.

The number and area statistics for wetland polygons (Table 2) give an estimate of the configuration of the landscape with respect to wetland components, and hence are indicative for landscape biodiversity. The complexity of wetlands in the landscape, as indicated by the size of uniform areas for mapped polygons, is least in the Arctic/Alpine zone, and is greater progressing towards the Coastal boreal zone. These results indicate that the landscape configuration along the coast generally provides the highest potential for wetland biodiversity, and that the potential decreases westwards towards the alpine zone.

It is known that the landscape near the Coastal boreal zone is more influenced by man's activities, and is ecologically younger owing to the ongoing glacio-isostatic land uplift (e.g. Svensson, 2002), consisting of patches of wetlands in earlier successional stages. The polygon sizes also indicate smaller areas (Table 2). These small patches tend to combine and merge together over time, such that in the oldest exposed parts of Northern Sweden, and the

Elevation zone	Mean number of wetland polygons per km^2 with standard errors	Minimum number of polygons per sample	Maximum number of polygons per sample	Mean wetland polygon area (m^2) with standard errors
1 Arctic/Alpine	19.3 (3.1)	1	73	11644 (3856)
2 Northern boreal	31.5 (3.7)	1	105	9208 (1233)
3 Upper middle boreal	39.6 (4.9)	4	91	7160 (821)
4 Lower middle boreal	22.0 (5.3)	1	55	6169 (1502)
5 Coastal boreal	25.3 (4.7)	1	47	6119 (763)
Total	28.9 (2.1)	1	105	8422 (957)

Table 2. Polygon statistics in the data set of 116 squares. Given are the mean, minimum and maximum number of polygons in a square, estimates of the number of wetland polygons per km^2, and the mean area per polygon in m^2, in the five Elevation Zones and the total study area.

parts with the greatest amounts of weakly sloping, flat and concave topographies, the wetlands would have had the longest time to develop and form larger homogeneous units.
The mean size of polygons in each square is positively correlated with the total wetland area (r = 0.330, P = 0.000, n = 116) which indicates that when there is higher wetland cover, it is formed by increasingly large sizes of polygons.

4.3 Relation of wetland area to height (elevation) above sea level

The Elevation Zones reflect a gradient in height above sea level, with the Arctic/Alpine zone having the highest mean height and the Coastal boreal zone having the lowest. Standard deviation shows how the variation in heights within squares varies. Standard deviation values are highest in the Arctic/Alpine zone, and lowest in the Coastal boreal zone (Fig. 2). The three interior zones have standard deviations that are quite similar, increasing only slightly in the Lower middle boreal zone. This indicates a similar degree of elevational variability of the landscapes there.
Simple Pearson correlations were done for the mean wetland areas with means of height (above sea level), standard deviation of height, and mean area of polygons per square. Mean wetland area is strongly negatively correlated with mean standard deviation of height (r = -0.367, P = 0.000, n=116), in other words, the lower the relief within a square, the greater the amount of wetland. Mean wetland area is not significantly correlated with height (r = -0.096, P = 0.305); this is explained by the bell-shaped relationship of wetland area to elevation, low in the Arctic/Alpine, higher in Northern boreal and Upper middle boreal, and dropping lower in Lower middle boreal and Coastal boreal (Fig. 3).
Even though non-significant the mean size of the polygons increased steadily from a low in the Coastal boreal to a high in the Arctic/Alpine zone (Table 2). However, polygon size was not correlated to elevation (r =0.011, P = 0.515). Polygon size was largest at intermediate elevations. In fact we would expect smaller polygons at higher elevations. The high value for polygon size in the Arctic/Alpine zone can be explained by the high variation of height within this zone. In addition to high elevation squares with smaller polygons it also contains a number of intermediate elevation squares with large mean polygon sizes.

5. Hydrotopographic types distribution and area

Each polygon was classified into Hydrotopographic wetland types, slightly modified after the wetland types used in the Swedish Wetland Inventory (Gunnarsson & Löfroth, 2009). Of the 18 wetland types (compared with 17 types in Swedish VMI), 14 were recorded in the 116 squares for northern Sweden. There were five types that were relatively common in terms of area and percentage of total wetlands: Flat (topogenous) fen with 44%, Sloping fen with 14%, Flat or weakly raised bog with 12%, String flark fen with 11%, and Non-mire wetland with 6% (Table 3, Fig. 5). Three other types achieved moderately low levels: Limnogenous fen 4%, String mixed mire 5%, and Mosaic mixed mire 3%. The remaining six types were quite uncommon. It is significant that Flat fens are by far the most abundant wetlands. It is also noteworthy that the Non-mire wetlands are among the more common of the wetlands.
The wetland types missing from the inventory were Plateau bog, Domed bog, Blanket bog, and Palsa mire. Plateau bogs and Domed bogs are more common in the south of Sweden where there is more heat and more precipitation, allowing these bogs to grow upwards into distinct raised bodies (similar to Finland, Seppä, 1996). Blanket bogs are missing in our

sample because the precipitation is too low (ca. 600 mm). They are rare in Sweden, but are found in Jämtland County where precipitation is high enough to allow their development (Götbrink & Haglund, 2010). Palsa mires were not found in the sample, but they do occur in the subalpine zone in the study area. Palsas from near Hemavan in Västerbotten (Zuidhoff & Kolstrup, 2000), and in three locations northwards in Norrbotten (Zuidhof, 2003), have been studied from the points of view of climatic data, soil temperatures, and geomorphological properties. Palsas are frozen peat structures that occur as the raised mound features of a mixed mire. They are difficult to recognize from aerial photos owing to their similarity to the small bog mound features in mixed mires at lower elevations.

Sloping bog and Net bog were both recorded only once in the sample in northern Sweden. Most sloping peat bodies in northern Sweden are minerotrophic sloping fens, sloping mixed mires with strings and flarks, or flark fens, by virtue of receiving some amount of input from mineral soil. However, large weakly sloping peatlands can become quite acidic and poor in base cations in their centres, and may only have scattered minerotrophic indicators (e.g., Carex rostrata). Net (patterned) bogs may be the result of the conflux of two weak flow patterns coming together approximately at right angles, which cause ridges to form at right angles to each other, eventually merging into net-shaped ridges. The flarks in the net-shaped ridges become isolated from mineral soil water influx, and eventually the whole net and flark complex becomes ombrogenous.

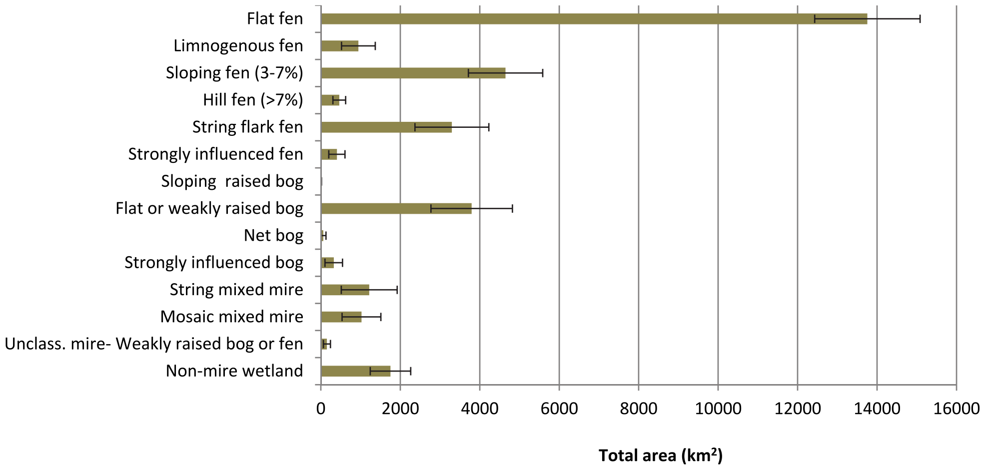


Fig. 5. Estimates of the total areas of the 14 Hydrotopographic mire types in the study area of Northern Sweden. Error bars indicate standard errors.

5.1 Hydrotopographic wetland types across five zones

In Table 3 we present the area percentage for the 14 types across the zones. We found that a majority of the types (eight) peaked in the Northern and Upper middle boreal zones. These two zones had also the highest proportion of wetland cover in total (Table 1). Most of the other six types had highest peaks in adjacent zones, and Hill fen which was most frequent in Arctic/Alpine had highest mean area in Upper middle boreal. Since there were only three Hill fen polygons sampled in the Upper middle boreal, at least one of these had a very large area.

The main wetlands characterizing the zones are:

1. **Arctic/Alpine** – Limnogenous fen, Hill fen, Unclassified mire, Weakly raised bog or fen – northern, Non-mire wetland.
2. **Northern boreal** – Flat fen, Sloping fen, String mixed mire.
3. **Upper middle boreal** – String flark fen, Flat or weakly raised bog, Mosaic-mixed mire.
4. **Lower middle boreal** – None of the Hydrotopographic types peak in this zone, but common types are Flat fens and Flat or weakly raised bogs.
5. **Coastal boreal** – Limnogenous fen and Strongly influenced (disturbed) fen.

Some of these distributions are as expected, e.g., the Sloping fens occur in terrains that have more relief and higher effective moisture regimes, and we expect the steeper Hill fens to be more common where there are steep hills and mountains with groundwater discharges and springs on lower and toe slopes. Strongly influenced fens peak in the Coastal boreal zone, but also occur in Lower and Upper middle boreal zones where the anthropogenic influences

Hydrotopographic wetland type	Arctic/ Alpine	Northern boreal	Upper middle boreal	Lower middle boreal	Coastal boreal	Total study area
Flat fen	4.49 (1.08)	**11.92** (1.89)	11.36 (1.86)	6.98 (1.96)	7.46 (2.01)	8.99 (0.87)
Limnogenous fen	**1.58** (1.10)	0.28 (0.13)	0.14 (0.09)	0.20 (0.16)	1.5 (1.47)	0.63 (0.28)
Sloping fen (3-7%)	2.85 (0.87)	**5.56** (1.75)	1.93 (0.58)	1.64 (1.26)	0.48 (0.36)	2.90 (0.58)
Hill fen (>7%)	**0.72** (0.34)	0.39 (0.23)	0.11 (0.09)	0	0	0.29 (0.10)
String flark fen	0.08 (0.08)	2.13 (0.83)	**4.53** (1.82)	2.19 (1.84)	0.65 (0.32)	2.19 (0.62)
Strongly influenced fen	0	0.06 (0.06)	0.36 (0.33)	0.19 (0.11)	**1.60** (1.15)	0.31 (0.15)
Sloping raised bog	0	0	**0.02** (0.02)	0	0	0.01 (0.01)
Flat or weakly raised bog	0.06 (0.05)	1.42 (0.93)	**4.90** (1.36)	4.72 (3.35)	1.29 (0.66)	2.54 (0.69)
Net bog	0	0.14 (0.14)	0	0	0	0.04 (0.04)
Strongly influenced bog	0	0	**0.56** (0.56)	0.30 (0.30)	0.35 (0.18)	0.23 (0.16)
String mixed mire	0	**2.28** (1.60)	0.26 (0.12)	0.07 (0.07)	0.60 (0.39)	0.76 (0.44)
Mosaic mixed mire	0.12 (0.13)	0.76 (0.52)	**1.69** (1.08)	0	0	0.68 (0.32)
Unclassified mire- Weakly raised bog or fen	**0.21** (0.21)	0.08 (0.07)	0.12 (0.11)	0	0.01 (0.01)	0.10 (0.06)
Non-mire wetland	**2.65** (1.32)	1.02 (0.52)	0.75 (0.29)	0.09 (0.04)	0.72 (0.41)	1.12 (0.33)

Table 3. Estimates of the percentage of terrestrial area for 14 Hydrotopographic types in five Elevation Zones and the total study area with standard errors in parentheses. The largest areas for each Hydrotopographic type across zones are indicated in bold.

have been greatest. The greatest frequencies of Limnogenous fen and Non-mire wetlands are in the Arctic/Alpine, which may relate to higher areas of floodplains in the upper reaches of rivers and along lakes there than in interior regions.

The Hydrotopographic types are defined on the basis of slope of the topography, flow patterns of the water, surface patterns of vegetation and Microtopographic elements, and the mineralogical characteristics of the water. A fundamental division is **minerogenous (fen)**, influenced to any degree by water derived from mineral soil, versus **ombrogenous (bog)** nourished only by rain water. Minerogenous is further subdivided into flat (**topogenous)** versus sloping **(soligenous)**. Surface movement of water and other complex interrelationships with the surface vegetation and near surface peat causes the formation of string or net patterns. One must take into account the influence of adjacent open water systems and occasional flooding, and this is done in the categories of **Limnogenous fens and Marsh.** Obviously, it is essential to develop diagnostic features for these conditions, and much of the NILS training consists of interpreting these features from features on the remote imagery. First and foremost is separating ombrogenous from minerogenous. This means using peatland form and vegetation to recognize bog as rounded or elongated peat bodies that are isolated from mineral soil water influence, and are flat or slightly raised in their centres.

We recognize several lines of variation or gradients of Hydrotopographic types within the classification:

1. Flat fens → Sloping fens→ Hill fens
2. Flat fens→Flat or weakly raised bogs
3. Sloping fens→Sloping bogs
4. Sloping fens →String flark fens→ String mixed mires→Net bog
5. String mixed mires→ Mosaic mixed mires→ Palsa mixed mires

It must be noted that the NILS inventory thus far does not distinguish the wetlands-peatlands-mires that are well-covered with trees, known as swamp forest, treed peatlands, and treed wetlands. These conditions have been assessed by Hånell (1989) and should be added to the NILS air photo interpretation scheme for a more complete representation of the total wetland-mire-peatland area. Many of the forested peatlands have been influenced or disturbed by drainage owing to long history of forest drainage to improve growth of trees. It has yet to be determined how the open wetlands-mires-peatlands included in NILS will merge with the treed wetlands. Undoubtedly the area of wetlands-peatlands will be considerably expanded when the treed wetland areas are added.

Some north-south gradients in distribution of types across the study area are discernible, indicating that there are higher frequencies of Sloping fen, Hill fen, Strongly influenced fen, Strongly influenced bog, and Mosaic mixed mire in the south. Higher percentages for the Strongly influenced fens and bog types in the south can most likely be explained by more frequent farming and forestry activities. Higher percentages of Limnogenous fens and Non-mire wetlands in the north may be related to a higher frequency of flooded lake and river margins and floodplains. There are also higher frequencies of String flark fens and String mixed mire types in the north, suggesting a more common occurrence of soligenous flow in sloping drainage ways and higher flooding stages during spring melt, which is associated with more frequent string and flark patterns.

6. Field and bottom cover

General classes of vegetation physiognomy are recognized under Field and bottom cover. In the photo interpretation, the most dominant class was assigned to each polygon. In Table 4 we summarize the occurrence of the Field and bottom cover types in the 3229 polygons. The most common types are Sphagnum (33.5%), Low sedge (21.1%), Dwarf shrub (17.6%), Graminoid/dwarf shrub (11.8%), Graminoid- and/or herb (6.8%), and Tall sedges/graminoids (3.3%). Five percent of the polygons were missing a field/bottom layer, probably owing to coverage by shadows, water, peat extraction, or dense cover of shrub or tree vegetation (the field/bottom layer is not registered when the trees have > 50 % crown cover).

In Table 4 we give a short, selected list of some dominant species that characterize the different Field and bottom layer types. Since the Field and bottom types were developed for air photo interpretation, they are necessarily quite broad and reflect main appearance and life form of the vegetation. Finer community types of course can be identified with the more detailed ground survey work that is done in each of the permanent squares. Many other species lists and descriptions of the wetland vegetation in northern Sweden can be found (e.g., Gunnarsson & Löfroth, 2009).

Field and bottom layer type	Occurrence (% of polygons)	Typical species
Field/bottom layer missing	5.0	Peat extraction or water, and polygons with > 50 % tree cover.
Graminoid and/or herb	6.8	Graminoids: *Carex rostrata*, *Carex lasiocarpa*, *Calamagrostis purpurea*, *Eriophorum angustifolium*, *Molinia coerula*; Herbs: *Dactylorrhiza* spp., *Menyanthes trifoliata*, *Potentilla palustris*.
Graminoid-dwarf shrub	11.8	See Graminoids above and Dwarf Shrubs below.
Dwarf shrub	17.6	*Andromeda polifolia*, *Betula nana*, *Calluna vulgaris*, *Empetrum nigrum*, *Ledum palustre*, *Vaccinium uliginosum*.
Lichen-dwarf shrub	0.1	See Lichen and Dwarf Shrub.
Lichen	0.2	*Cetraria islandica*, *Cladonia mitis*, *C. rangiferina*, *Racomitrium lanuginosum*.
Reeds	0.1	*Phragmites australis*, *Typha latifolia*, *Iris pseudacorus*.
Tall sedges/graminoids	3.3	*Equisetum fluviatile*, *Scirpus lacustris*, *Carex acuta*, *C. aquatilis*, *C. rostrata*, *C. lasiocarpa*.
Low sedge	21.1	*Carex chordorrhiza*, *C. livida*, *Eriophorum vaginatum*, *Rhynchospora alba*, *Trichophorum alpinum*, *T. cespitosum*.
Sphagnum mosses	33.5	*Sphagnum balticum*, *S. capillifolium*, *S. cuspidatum*, *S. fuscum*, *S. papillosum*, *S. squarrosum*, *S. tenellum*.
Other mosses	0.6	*Scorpidium scorpioides*, *Campylium stellatum*, *Drepanocladus revolvens*, *Tomenthypnum nitens*.
Logging residues	0.0	Branches, twigs and leaves.
Layer cannot be interpreted	0.1	Shadows from structures on the ground or from clouds obstruct the view.

Table 4. Field and bottom cover Types, and percent frequency of the types in the data set (3229 total polygons), and typical abundant species for each type.

The field and bottom cover types can be broadly related to the moisture and water table gradient. Dwarf shrubs, Lichen-dwarf shrubs, and Lichen types are well developed on hummock and mound levels of the microtopographic gradient. Graminoid and/or herb, and Graminoid-dwarf shrub are common types of lawns in fens or bogs. Low sedges are in the carpet phases of fens and bogs. Sphagnum occurs widely across the whole wetland gradient, except for frequently flooded sites and strongly shaded sites (trees, dense shrubs). Reeds and tall sedges/graminoids are on shores and frequently flooded locations, often with higher pH and base-richness. Often there is a Sphagnum bottom layer beneath the dwarf shrub, graminoid, and low sedge types.

There are also general relationships of these Field and bottom cover types with the pH-base-richness gradient. Dwarf shrub and dwarf shrub-lichen tend to have quite low pH-base status and are in bogs or in the bog phase of mixed mires. The sequence tall graminoids, graminoids, and low sedges tend to follow a gradient of high to low pH-base levels. *Sphagnum*-rich sites have a range of species that differentiate both on a moisture-water table gradient and a pH-base richness gradient from rich to poor fen and into ombrogenous bog. Tall reeds and emergents, floating plants, and submerged plants are in water at edges of rivers and lakes, and vary from circumneutral to weakly acid and moderate to low base levels.

6.1 Relationships of Field and bottom cover to Hydrotopographic types

To explore relationships of the field and ground layer vegetation with hydrotopographic types we reduced the data set to the six most common Field and bottom types, and the eight

Hydrotopographic wetland type	Fewer occurrences than expected of Field/bottom layer	Higher occurrences than expected of Field/bottom layer
Flat fen (all types of field/bottom occur)	Graminoid/herb, Graminoid/Dwarf shrub, and Dwarf shrub.	Low sedges and Sphagnum mosses.
Limnogenous fen	Graminoid/Dwarf shrub, Dwarf shrub, and Sphagnum mosses.	Graminoid/herb, Tall and Low sedges.
Sloping fen	Graminoid/herb, Dwarf shrubs and Tall sedges.	Graminoid/dwarf shrub and Low sedges.
String flark fen	Graminoid mixtures with Herb Graminoid/Dwarf shrub, Dwarf shrub.	Low sedges and Sphagnum mosses.
Flat or weakly raised bog	Graminoid/herb, Tall sedges, and Sphagnum mosses.	Graminoid/Dwarf shrub and Dwarf shrub.
String mixed mire	Graminoid/herb, Graminoid/Dwarf shrub, and Tall sedges.	Dwarf shrub and Sphagnum mosses.
Mosaic mixed mire	Graminoid/herb, Tall sedges, and Sphagnum mosses.	Graminoid/Dwarf shrub and Dwarf shrub.
Non-mire wetland	Dwarf shrub, Low sedges and Sphagnum mosses.	Graminoid/herb, Graminoid/Dwarf shrub, and Tall sedges.

Table 5. The relations between the Hydrological mire type and associated Field/bottom layers in the dataset, from analyses with Chi-square test.

most common Hydrotopographic types. By summarizing the results from a Chi-square analysis, the relation of Field/bottom types to different Hydrotopographic wetland types can be seen (Table 5). The relationship is such that if the observed is higher than the expected by random, there is a positive association, while if it is lower there is a negative association. For example, Graminoid herb was rather strongly and positively associated with Limnogenous fen and Non-mire wetland, while Sphagnum type was strongly positively associated with Flat Fen, and strongly negatively associated with Flat or weakly raised bog.

From this analysis it is possible to indicate, in a general way, the main kinds of Field and bottom layers associated with each Hydrotopographic mire type. However, it is concluded that one cannot very reliably use Field/bottom layer type to indicate Hydrotopographic type, or vice versa. Instead one must use such defining attributes as, flow patterns, peatland shape, and physiographic location to classify polygons. And for Field / bottom layer classification one must rely on the dominant life form.

7. Microtopographic series

The definition of these types was based upon the microtopographic series - hummock, lawn, carpet, mud-bottom, pool series – introduced by Sjörs (1948) and now used internationally (e.g., Rydin and Jeglum 2006). Seven elements are recognized in the NILS system: Dwarf shrub dominated hummock, lawn, carpet, mud-bottom, flark pool, bog pool, and marsh. (Marsh as described in Rydin and Jeglum, 2006, is very similar to Sumpkarr as described in Allard, 2005). In conducting the photo interpretation, these types together should add up to 100% cover. In the data explored here hummock or lawn were the most common types, and often together totalled 100%. There was a strong inverse correlation between the values for these two types, with a Pearson r value of -0.635, P-Value < 0.0001.

The area data for Microtopographic series in the polygons are given in Table 6, showing that the most common elements are, in decreasing order: Lawn, Hummock, Carpet, and Mud-bottom. Flark pool, Bog pool, and Marsh were very infrequent.

Microtopographic element	Total area (km^2) with standard errors		Proportion of total mire area with standard errors	
Hummock asterisk	8423	(1196)	30.51	(2.64)
Lawn	11272	(1149)	40.83	(2.47)
Carpet	5614	(816)	20.33	(1.72)
Mud-bottom	1886	(557)	6.83	(1.61)
Flark pool	329	(180)	1.19	(0.56)
Bog pool	82	(30)	0.30	(0.10)
Marsh	62	(32)	0.23	(0.10)

*Small raised mounds usually built-up by Sphagnum and characterized by dwarf shrubs.

Table 6. Estimates of total areas of mires of seven Microtopographic elements, and proportions of the total mire area studied, with standard errors (in parentheses).

We performed a chi-square between Microtopographic series and Hydrotopographic wetland types to determine relationships between the two classifications. Those comparisons of observed and expected with enough values showed some interesting relationships. In Flat or weakly raised bog, Strongly influenced bog, and String mixed mire, hummocks were more abundant than lawns, probably because of more of the raised bog phase in these types. Carpets were more frequent than the mud-bottoms in all the Hydrotopographic types. Flark pools were distributed unevenly, and observed counts were lower than expected in Flat fen, Sloping fen, and Flat or weakly raised bog, but higher than expected in String flark fen and String mixed mire. Clearly the sample method was able to pick up the flark element. Pools were more common than expected in Flat fen whereas Marsh was less common than expected in Flat fen. However, Marsh was more common in Limnogenous fen, just as one would expect along lake and stream margins.

Because it is deemed so important for interpreting climate change to be able to accurately determine the proportions of each Microtopographic element, we give detailed descriptions of the elements which follow and augment the descriptions of Rydin & Jeglum (2006):

Hummocks - Hillocks or small mounds with rounded, convex form, usually formed of hummock *Sphagnum* species (e.g. *S. fuscum, S. capillifolium*) rising to ca. 30-60 cm above adjacent hollows. Water tables range from 20-50 cm below the tops of the hummock. Sphagnum may be the main cover viewed from above, without any overtopping vegetation. However, usually the Sphagnum is covered with dwarf shrubs (e.g., *Calluna vulgaris, Ledum palustre, Vaccinium uliginosum*), and sometimes may be partially covered by patches of lichen (e.g., *Cladonia* spp.). With climate warming and lowering of water tables dwarf shrubs and lichens will probably increase, as will sapling and tree cover, on the hummock phase. Hummocks can occur as the dominant microtopographic element in raised bogs, with smaller amounts of hollow types (Rydin & Jeglum, 2006), or they may form raised linear strings or miniature bog islands surrounded by lawns and other wetter elements in patterned bogs, net bogs, and mixed mires.

Lawns - Level surfaces covered with fairly dense cover of graminoids (tall sedges, grasses, e.g., *C. lasiocarpa, C. rostrata, Eriophorum vaginatum*). Most of the time lawns surfaces are 5-20 cm above the water table, but during spring melt and heavy rains water can be at or slightly above the surface. Because of the strong rooting systems of the graminoids, lawns are so firm that footprints rapidly disappear. The moss cover beneath the graminoids is continuous, and lawns seem to have the greatest bryophyte diversity.

Carpets - Level surfaces with moderate to sparse cover of low sedges (e.g., *Carex livida, Rhynchospora alba, Scirpus cespitosus)* and Sphagnum and/or brown mosses in the bottom layer. Most of the time lawns surfaces are from 5 cm below to 5 cm above water table, but during spring melt and heavy rains water can be more than 5 cm above the surface. The lack of strong graminoid rooting systems makes carpets so soft that a footprint remains visible for a long time.

Mud-bottoms – Mud-bottoms are often inundated by water and then are dark to black and hard to separate from the adjacent flark pools or bog ponds. However, in summer drought, mud-bottoms may be exposed bare peat, and may have thin covering of algae, or a gelatinous layer of decomposing peat and microorganisms, or a layer of dark green to black liverwort (e.g., *Cladopodiella fluitans*) with some scattered horizontal shoots of mosses.

Flark pools, bog pools: These are water-covered, and appear very dark to black. They have elongated, crescentic or more or less rounded shapes. Flark pools are the elongated pools in minerogenous fens with unidirectional flow, whereas bog pools are either crescentic or rounded shapes in ombrogenous bogs (Rydin Pers. Comm.). Even though flark pools and bog pools are supposed to be in fens and bogs respectively, sometimes it is difficult to determine positively whether the type in which the pool occurs is a bog or a fen. Hence, there may be misidentifications of flark pools (and other fen pools) and bog pools.

Only one Field/bottom type was assigned to each polygon, whereas the Microtopographic series had a range of seven classes which were given percentages if present in a polygon. Therefore the detail of sampling is greater for the Microtopographic elements. The accuracy of the estimates of covers for different elements should be explored further by conducting assessments of well-mapped wetland polygons, and comparing several photo interpreters. Such exercises are conducted for the staff of NILS as thematic blocks, and are extremely valuable for training and to develop more reliable estimates. This is particularly important because the Microtopographic elements are key attributes in documenting effects of climate change and anthropogenic influences. In addition, it would be of value to define an additional element, i.e., hummock with trees (treed hummock) to allow for documentation of tree

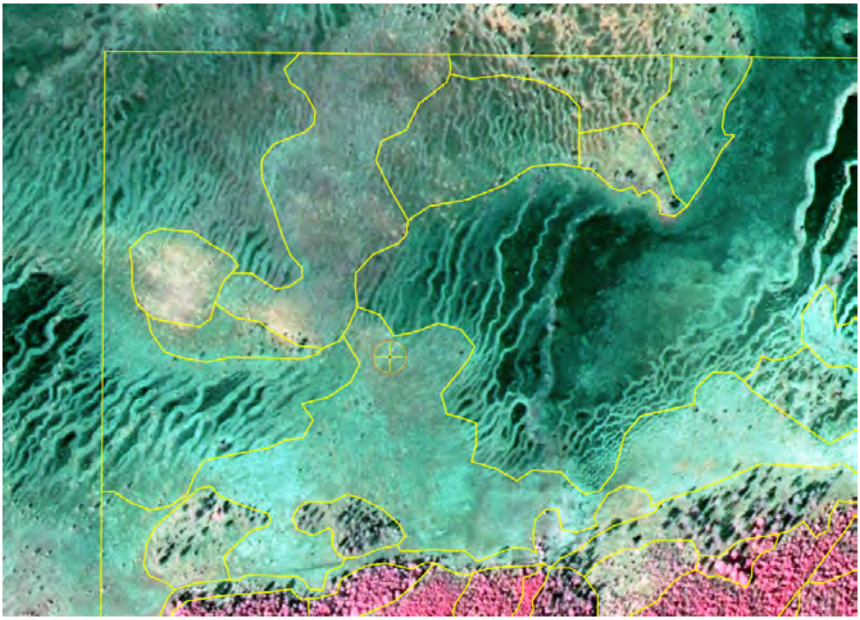


Fig. 6. A portion of a NILS square (yellow lines left and top) in the mid-south of the study area rich in String flark fens. Yellow lines encircle the mapped polygons. The diameter of the circle with the cross hair (centre left) is 20 m. Inside the flark pools can be only water, or water plus mud-bottoms, or only mud-bottoms; therefore flark pools and mud-bottoms could be combined in assessing climate change. In the upper left are some areas in which the unpatterned sedge fens are either very light or medium grey-pink; combinations of lawns and carpets could be more reliable indicators of climate change.

encroachment onto peatlands (e.g., Fig. 1). We also suggest that it may be useful in future analyses to combine i) lawn and carpet, and ii) mud-bottom with flark pools (e.g., Fig. 6). These elements individually have low accuracy of estimation, but by combining these pairs we may achieve more accurate and reliable estimations of cover changes.

8. Use of monitoring data for biodiversity and climate change

The NILS program covers all terrestrial habitats in Sweden, including wetlands and peatlands. Moreover, NILS also includes the alpine area of the Scandinavian Mountain Range and the various shallow-peated wetlands that harbour a rich diversity of habitats and flora. The long-term series of data that will be made available have a substantial potential for various purposes. With the 5-year inventory cycle of the NILS programme it should be possible to observe changes of vegetation that may relate to climate change, as well as anthropogenic influences such as various land use activities and atmospheric pollution. Below we present a list of possible wetland and peatland ecosystem changes that may be observed, having in mind future improvements and supplementary research within the NILS monitoring system.

1. **Shifts in temperature and moisture regimes will cause biological responses**: With increases in temperature, we expect increased evapotranspiration, decreases in water level, and increased decomposition in warmer acrotelms. However, there are predicted to be net positive or negative changes in precipitation, which may move different habitats toward wetter or drier conditions (Lind et al., 2008). If the net effect of the changes is towards warming, the vegetation will have net increases in biomass. Tall woody vegetation, dwarf shrubs, *Carex* and other graminoids, herbs, *Sphagnum*, other mosses, liverworts, and lichens will all respond to the effects of climate changes, with changes in metabolic processes (photosynthesis, productivity, respiration), and this will translate to changes in decomposition rates and net accumulation or loss of peat (Mooney, 1991).
2. **Changes in the Field and bottom layers:** The changes will not be uniform, but rather will change in different directions depending on the pH-base saturation status. Dwarf shrub types will develop denser cover with increased shading and litterfall over *Sphagnum*. In the case of Graminoid types, it is probable that productivity will increase and canopies become taller and more lush owing to response to increased release of nutrients from more rapid decomposition and cycling in deeper acrotelms. For these same reasons, tall graminoids may gain at the expense of low graminoids. Sphagnum will probably decrease in general owing to being covered by litterfall of more rapidly growing field layers. Lichen cover will probably increase. Tall sedge, Limnogenous fen, and Non-mire wetlands could increase if precipitation increases, causing higher/more frequent flooding.
3. **Changes in relative abundances of Sphagnum:** Hummock species of Sphagnum will increase over lawn and carpet Sphagnums. Mauquoy *et al.* (2002) showed from peat core analyses that in periods with lower temperature, due to decreased solar activity, there was a shift in representation from lawn and hummock species to hollow species in ombrotrophic mires in Denmark and the UK. Breeuwer et al. (2008) performed greenhouse warming studies with species from sites in southern and northern Sweden.

They predict that in northern Sweden, hollow species such as *S. balticum* will lose competitive strength relative to hummock species such as *S. fuscum* and southern species such as *S. magellanicum*.

4. **Changes in proportions of Microtopographic elements**: Most of these changes will be owing to the changes in Sphagnum dominance just mentioned. With higher temperatures, increasing evapotranspiration, and lowered water tables, bogs will change in the direction of more hummock and treed hummock vegetation elements. Hummocks with dwarf shrubs will invade into the lawns. Soft carpets may become drier and develop towards lawns, while mud-bottoms may develop towards soft carpets. The area of open water flarks and pools may decrease. The Hydrotopographic types that are transitional between bog and fen such as Flat or weakly raised bog and Weakly raised bog or fen-northern, may develop toward more hummock-preferring Sphagnum and develop a more ombrogenous bog ecosystem, owing to less influence of minerogenous waters.
5. **Changes owing to drainage:** Drainage effects can be used to predict what will happen with climate warming and drying. Many of the same changes listed under Items 2-4 may occur by lowering water tables. This has and still is occurring extensively owing to forest drainage in Sweden, Finland, and the Russian Federation. Drainage of Flanders Moss in Scotland has shown conversion of most of its previous lawn vegetation to hummock vegetation, and only a little of the carpet and pool vegetation is left in small pockets (Pers. Obs.). Hebda *et al.* (2000) estimated the zone of influence of water table lowering in Burns Bog, a bog on the Fraser River Delta in southern British Columbia, Canada, to extend over 100 m from a peripheral ditch.
6. **Expansion of the density and cover of trees into peatlands.** Such expansions are often owing to lowered water tables, best illustrated by the expansion of trees in drained peatlands (e.g., see Fig. 1). Several studies have documented advances of trees and shrubs from the margins into the centres of peatlands (e.g., Hebda et al., 2000; Linderholm and Leine, 2004), and the dying of Sphagnum at the margins by lowered water levels and being covered by forest litter. The NILS monitoring in 5-year intervals is ideally suited to recording changes in canopy cover of trees and saplings.
7. **Changes of vegetation and invasive species.** Striking examples are the invasion by bamboo, *Sasa* sp., into drained mires in Japan (Iqbal et al., 2005); and Reed Canary Grass (*Phalaris arundinacea*) into bog owing to marginal flooding by mineral-rich waters (Burns Bog, British Columbia, Canada, Pers. Obs.). With drying of peatland margins in Burns Bog, British Columbia, drier upland forest trees such as *Betula* spp and *Tsuga heterophylla*, shrubs such as *Gaultheria shallon* and *Rubus* spp., other upland herbs, and dry mosses (e.g., feathermosses) have invaded and laid down a forest humus, and this process is progressing toward the centre of the peatland (Hebda et al., 2000).
8. **Decreases in peat depth at the margins of the peatlands, and decreases of total area of peatlands:** This will happen owing to temperature increase and drying, collapse of the peat matrix owing to water loss out of the matrix, and oxidation and decomposition. In the first decade after forest drainage, subsidence of peat may be in the order of 15 to 40 cm (Päivänen & Paavilainen, 1996). National Forest Inventories in Finland over many decades (Keltikangas et al., 1986) suggest that significant areas of shallow-peated sites have converted to non-peatland with less than 30 cm depth of peat.

9. **Melting of permafrost or palsas in alpine-subalpine zone:** Palsas and palsa melting are key indicators of climate and climate warming (Sollid & Sørbel, 1998; Zuidhoff, 2003). Increases of percent of water cover, expressed as thermokarst and melt lakes, may be an early indicator of permafrost melting (Callaghan et al., 2002). Permafrost thawing is likely to change the flow pathways taken by water as it moves through arctic and subarctic landscapes, and there may be increases in the content of dissolved organic carbon in waterways and lakes in subarctic catchments (e.g., Lyon et al., 2009).
10. **Changes in bog processes: peat decomposition and accumulation, nutrient cycling, and greenhouse gases:** A large amount of research has been done concerning peat accumulation, decomposition, and release of CH_4 and CO_2 greenhouse gases relative to climate change (e.g., Strack et al., 2004). Decomposition rates increase with temperature and increased N availability, and hummock species decompose slower than hollow species (Limpens et al., 2003). There is a great deal of uncertainly, however, in predicting the effect of climate change on the carbon cycling in peatlands (e.g., Moore et al., 1998).

9. Acknowledgements

We are grateful to Erik Cronvall for the help that he provided in the processing of the data and for help with the GIS problems. We also thank the diligent inventory staff of the NILS aerial photography inventory, Per Andersson, Sofia Andreassen, Merit Kindström, Anders Lindblad, Björn Nilsson, Maud Tyboni and Marianne Åkerholm.

10. References

Allard, A., Nilsson, B., Pramborg, K., Ståhl, G. & Sundquist, S. (2005). *Manual for aerial photo interpretation in the National Inventory of Landscapes in Sweden, NILS, year 2003*. Swedish Univ. Agricultural Sciences (SLU), Department of Forest Resource Management and Geomatics.

Allard, A., Löfgren, P. & Sundquist, S. (2004). *Skador på mark och vegetation i de svenska fjällen till följd av barmarkskörning.* (*Mechanical damage of ground and vegetation in the Swedish Mountains as a consequence of vehicle driving during summer*), Swedish Univ. Agricultural Sciences, Department of Forest Resource Management, Work Report No. 126,

Allard, A., Cronvall, E., Nilsson, B., Kindström, M., Pramborg, K., Ståhl, G. & Sundquist, S. (2010). *Instruktion för bildtolkningsarbetet vid Nationell Inventering av Landskapet i Sverige, NILS, år 2006. (Manual for aerial photo interpretation in the national inventory of landscapes in Sweden NILS, year 2006)*, Swedish Univ. Agricultural Sciences, Department of Forest Resource Management.

Breeuwer, A., Monique, M.P.D., Heijmans, B.J.M. Robroek, & Berendse, F. (2008). The effect of temperature on growth and competition between Sphagnum species. *Oecologia* 156: 155-167.

Callaghan, T.V., Crawford, R.M.M., Eronen, M., Hofgaard, A., Payette, S., Rees, W.G., Skre, O., Sveinbjörnsson, B., Vlassova, T.K. & Werkman, B.R. (2002). The dynamics of the tundra-taiga boundary: An overview, suggested coordinated and integrated approach to research. *Ambio Special Report,* No. 12:3-5.

Christensen P., Glimskär A., Hedblom M. & Ringvall A. (2008). *Myrarnas areal och vegetation: skattningar från provytedata i NILS 2003-2007 (Mire area and vegetation: estimations from field sample data in NILS 2003-2007)*. Swedish Univ. Agricultural Sciences (SLU), Department of Forest Resource Management, Work Report No. 237.

Dale, V. H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F.J. Stocks, B.J. & Wotton, B.M. (2001). Climate change and forest disturbances. *BioScience* 51 (9):723–734.

Gorham, E. (1991). Northern peatlands: role in the carbon cycle and probable responses to global warming. *Ecol. Appl.* 1:182.

Gorham, E. (1995). The biogeochemistry of northern peatlands and its possible responses to global warming. In Woodwell, G.M. & MacKenzie, F.T. (eds.), *Biotic feedbacks in the global climatic system: will the warming speed the warming?*, Oxford Univ. Press, pp.169-187.

Gorham, E., Brush, G.S., Graumlich, L.J., & Johnson, A.H. (2001). The value of paleoecology as an aide to monitoring ecosystems and landscapes, chiefly with reference to North America. *Environ. Rev.* 9:99-126.

Government of Sweden. (2009). *Regeringens proposition 2009/10:55. Svenska miljömål, för ett effektivare miljöarbete. (Governemnt Proposition, Swedish Environmental Quality Objectives as a tool for more effective environmental work*), Available from: http://www.sweden.gov.se/content/1/c6/14/24/56/dca35b38.pdf

Gunnarsson, U. & Löfroth, M. (2009). *Våtmarksinventeringen – resultat från 25 års inventeringar. Nationell slutrapport för våtmarksinventeringen (VMI) i Sverige, (The Wetland Inventory – Results from 25 years of inventory. Final report from the National Wetland Inventory (VMI) in Sweden)*, Swedish Environmental Protection Agency, Report 5225.

Götbrink, E. & Haglund, A, (2010). *Manual för uppföljning i myrar i skyddade områden*. (*Manual for continued monitoring of mires in protected areas, A field manual for follow-up on European Habitats Directive*), Swedish Environmental Protection Agency, Typescript. Available from:
http://naturvårdsverket.se/upload/04_arbete_med_naturvard/Skydd_och_skotsel_vardefull_natur/Uppfoljning/7_ufmanual_myrar_faststalld20100503.pdf

Hånell, B. (1989). *Skogliga våtmarker I Sverige (Peatlands in Sweden. A description of forest conditions on shallow and deep peatlands and their national and local distribution)*. Swedish Univ. Agricultural Sciences, Department of Forest Soils, Rep. 60.

Hebda, R. J., Gustavson, K., Golinski, K. & Calder, A. M. (2000). *Burns Bog Ecosystem Review –Synthesis Report for Burns Bog, Fraser River Delta, South-western British Columbia*, Environmental Assessment Office, Victoria, BC, Canada.

Helmfrid, S. (1996). *Sveriges geografi (Geography of Sweden)*, National Atlas of Sweden Series, SNA, Swedish Land Survey, Vol. 17.

Ihse, M. (2007). Colour infrared aerial photography as a tool for vegetation mapping and change detection in environmental studies of Nordic ecosystems: A review. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography* 61(4), 170-191.

Joosten, H. & Clarke, D. (2002). *Wise use of mires and peatlands – background and principle including a framework for decision-making*. Internatl. Mire Conserv. Group and Internatl. Peat Soc. Saarijärvi Offset Oy.

Keltikangas, Laine, J., Puttonen, P. & Seppälä, K.M. 1986. Vuosina 1930-1978 metsäojitetut suot: Ojitusalueiden inventoinnin tuloksia. Abstract: Peatlands drained for forestry during 1930-1978: Results from field surveys of drained areas. *Acta For. Fenn*. 193:1-194.

Lennartsson, T. & Stighäll, K. (2005). *Landmiljöer i kust och skärgård* (*Land environment at coasts and archipelagos*), Swedish Environmental Protection Agency, Report 5482.

Limpens, J., Tomassen, H.B. & Berendse, F. (2003) Expansion of Sphagnum fallax in bogs: striking the balance between N and P availability. *Journal of Bryology* 25, pp 83-90.

Lind, P. & Kjellström, E. (2008). *Temperature and precipitation changes in Sweden; a wide range of model-based projections for the 21st century*. Swedish Meteorological and Hydrological Institute, SMHI, RMK, No. 113.

Linderholm, H.W. & Leine, M., (2004). An assessment of Twentieth Century tree-cover changes on a southern Swedish peatland combining dendrochronology and aerial photograph analysis. *Wetlands* 24(2):357-363

Lyon, S.W., Destouni, G., Giesler, R., Humborg, C., Mörth, M., Seibert, J., Karlsson, J. & Troch., P.A. (2009). Estimation of permafrost thawing rates in a sub-arctic catchment using recession flow analysis. *Hydrol. Earth Syst. Sci.* 13:595–604.

Löfroth, M. (1991). *Våtmarkerna och deras betydelse*. (*The wetlands and their importance*), Swedish Environmental Protection Agency, Report 3824.

Mauquoy, D., van Geel, B., Blaauw, M. & van der Plicht, J. (2002). Evidence from northwest European bogs shows 'Little Ice Age' climatic changes driven by variations in solar activity. *Holocene* 12, 1-6.

Mooney, H.A. (1991). Biological response to climate change: An agenda for research. *Ecological Applications* 1, 112-117.

Moore, T.R., Roulet, N.T., & Waddington, J.M. (1998). Uncertainty in predicting the effect of climate change on the carbon cycling of Canadian peatlands. *Climatic Change* 40:229-245.

Morgan, J.L., Gergel, S.E. & Coops, N.C. (2010). Aerial photography: A rapidly evolving tool for ecological management. *Bioscience* 60(1):47–59.

National Wetlands Working Group. (1988). *Wetlands of Canada*. Environment Canada, Ottawa.

Nordic Council of Ministers. 1977. *Naturgeografisk regionindelning av Norden*. (*Natural geographic regions of the Nordic Countries*), NU–serien 1977 (34: 1–137).

Noss, R.F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* 4, 355-364.

Paavilainen, E. & Päivänen, J. (1995). *Peatland forestry: Ecology and principles. Ecological Studies*, Vol. III. Springer-Verlag, Berlin.

Päivänen, J. & Paavilainen, E. (1996). Forestry on peatlands. In Vasander, H. (ed.), *Peatlands in Finland*. Finnish Peatland Society, Helsinki, pp.72-83.

Persson, G., Bärring, L., Kjellström, E., Strandberg, G. & Rummukainen, M. (2007). *Climate indices for vulnerability assessments*. Swedish Meteorological and Hydrological Institute (SMHI), RMK No. 111. Norrköping.

Renman, G., 1989. *Barmarkskörning på fjällen. Effekter av körning med terränghjulingar på mark och vegetation*. (*Vehicle driving during summer in the Swedish Mountains. Effects of driving with off-road vehicles on ground and vegetation)*, Swedish Environmental Protection Agency, Report 3598.

Rydin, H., Sjörs, H., & Löfroth, M. (1999). Mires. *Acta Phytogeographica Suecica* 84: 91–112.

Rydin, H. & Jeglum, J.K. (2006). *The Biology of Peatlands*. Oxford University Press. Oxford.

Seppä, H. (1996). The morphological features of the Finnish peatlands. In Vasander, H. (ed.), *Peatlands in Finland*. Finnish Peatland Society, Helsinki, pp. 27-33.

Sollid, J.L. & L. Sørbel. (1998). Palsa bogs as a climate indicator: examples from Dovrefjell, southern Norway. *Ambio* 27(4:287-291).

Strack, M. (ed.) (2008). *Peatlands and climate change*. International Peat Cong. Tulamoor, Ire.

Strack, M., Waddington, J.M., & Tuittila, E.-S. (2004). Effect of water table drawdown on northern peatland methane dynamics: Implications for climate change. *Global Biogeochem. Cycles* 18, GB4003, doi:10.1029/2003GB002209, 2004.

Ståhl, G., Allard, A., Esseen, P.-A., Glimskär, A., Ringvall, A., Svensson, J., Sundquist, S., Christensen, P., Gallegos Torell, Å., Högström, M., Lagerqvist, K., Marklund, L., Nilsson, B., & Inghe, O. 2011. National Inventory of Landscapes in Sweden (NILS) - scope, design, and experiences from establishing a multiscale biodiversity monitoring system. *Environmental Monitoring and Assessment* 173: 579-595.

Svensson, J. (2002). Succession and dynamics of Norway spruce communities on Gulf of Bothnia rising coastlines. PhD Thesis, *Acta Universitatis Agriculturae Suecicae - Silvestra* 239.

Svensson, J., Allard, A., Christensen, P., Eriksson, Å. & Glimskär, A. (2009), Glimskär, A. & Sandring, S.. Landscape biodivesity monitoring in the Swedish NILS program. *XIII World Forestry Congress, Buenos Aires, Argentina, Conference Proc*. p.8.

Tarnocai, C. (2006). The effect of climate change on carbon in Canadian peatlands. *Global and Planetary Change* 53, pp. 222–232.

Warner, B.G. & Asada, T. (2006). Knowledge gaps and challenges in wetlands under climate change in Canada. In Batti, S., Lal, R., Apps, M.J. & Price, M.A. (eds.), *Climate change and managed ecosystems,* CRC Press, Taylor and Francis Group, Boca Raton FL, pp. 355-371.

Zuidhoff, F.S. (2003). *Palsa growth and decay in Northern Sweden*. PhD Thesis, Uppsala Univ., Uppsala, Sweden. Comprehensive summaries of Uppsala Dissertations from the Faculty of Science and Technology 813.

Zuidhoff, F.S. & Kolstrup, E. (2000). Changes in palsa distribution in relation to climate change in Laivadalen, Northern Sweden, especially 1960-1997. *Permafrost and Periglacial Processes* 11:55-69.