

The role of local and landscape level measures of greenness in modelling boreal plant species richness

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ABSTRACT

Measurements of primary productivity and its heterogeneity based on satellite images can provide useful estimates of species richness and distribution patterns. However, species richness at a given site may depend not only on local habitat quality and productivity but also on the characteristics of the surrounding landscape. In this study we investigated whether the predictions of species richness of plant families in northern boreal landscape in Finland can be improved by incorporating greenness information from the surrounding landscape, as derived from remotely sensed data (mean, maximum, standard deviation and range values of NDVI derived from Landsat ETM), into local greenness models. Using plant species richness data of 28 plant families from 440 grid cells of 25 ha in size, generalized additive models (GAMs) were fitted into three different sets of explanatory variables: (1) local greenness only, (2) landscape greenness only, and (3) combined local and landscape greenness. The derived richness–greenness relationships were mainly unimodal or positively increasing but varied between different plant families, and depended also on whether greenness was measured as mean or maximum greenness. Incorporation of landscape level greenness variables improved significantly both the explanatory power and cross-validation statistics of the models including only local greenness variables. Landscape greenness information derived from remote sensing data integrated with local information has thus the potentiality to improve predictive assessments of species richness over extensive and inaccessible areas, especially in high-latitude landscapes. Overall, the significant relationship between plants and surrounding landscape quality detected here suggests that landscape factors should be considered in preserving species richness of boreal environments, as well as in conservation planning for biodiversity in other environments.

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1. Introduction

The amount of energy available in a system, often measured as primary productivity, is thought to be an important determinant of species richness (Currie, 1991; Rosenweig, 1995; Hawkins et al., 2003). The relationship between productivity and species richness may take either a monotonically increasing (or asymptotically leveling off) or a unimodal (highest richness encountered at intermediate productivity levels) form (Waide et al., 1999; Gross et al., 2000; Aarssen, 2001; Mittelbach et al., 2001; Braschler et al., 2004). Indeed, a multitude of studies and meta-analyses has focused on attempts to develop generalizations of the form of species richness–productivity relationships, but their outcomes have remained controversial, giving support to the predominance of unimodal (e.g. Waide et al., 1999; Mittelbach et al., 2001) or posi-

tive relationships (e.g. Whittaker and Heegaard, 2003; Gillman and Wright, 2006).

Identifying appropriate surrogates for direct measurements of net primary productivity can also be a challenge, especially at coarser scales (Whittaker and Heegaard, 2003; Gillman and Wright, 2006). An increasing number of studies conducted at landscape or regional scales (Mittelbach et al., 2001) have demonstrated the usefulness of primary productivity estimates derived from remote sensing (RS) in the modelling of species richness (Gould, 2000; Nagendra, 2001; Kerr and Ostrovsky, 2003a; Pettorelli et al., 2005). Normalized difference vegetation index (NDVI) is sensitive to photosynthetically active biomass, correlated with leaf area index; and related to amount of absorbed photosynthetically active radiation (Tucker, 1979). In particular, NDVI has been employed as an estimate of primary productivity (Box et al., 1989; Reed et al., 1994; Cramer et al., 1999), as well as its heterogeneity (Rocchini et al., 2004), and thus it may provide a useful predictor for richness patterns (O'Brien et al., 2000; Mittelbach et al., 2001; Benayas and Scheiner, 2002). NDVI correlates strongly with plant biomass and it is one of the most

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direct available estimates for ecosystem productivity, especially in seasonal and in drier and/or colder environments with wide ranges of NDVI values (Box et al., 1989; Oindo and Skidmore, 2002; Kerr and Ostrovsky, 2003b; Pettoirelli et al., 2005; Levin et al., 2007).

The use of remote sensing also includes further potential benefits, as RS data offers an inexpensive means of deriving complete spatial coverage of environmental information for large areas in a consistent and regular manner (Muldavin et al., 2001; Foody and Cutler, 2003).

Species richness is a scale-dependent phenomenon (Ricklefs, 1987; Rosenzweig, 1995; Mittelbach et al., 2001). Especially in fine-grained studies employing small sample plots, parameters measured from the site itself, and related to resource availability or having a direct impact on plant growth or survival (Pausas and Austin, 2001; Pausas et al., 2003), are crucial. However, ecological processes at a particular site are often also affected by broader scale processes in the surrounding landscape (Austin, 1999; Pearson, 2002; Piessens et al., 2004). Thus, the quality of the neighbouring landscape (i.e. “landscape effect”) may have a strong influence on local species richness (Pulliam and Danielson, 1991; Dunning et al., 1992), separately from the local conditions. Because of this, improving the understanding of the “landscape effect” on species richness is an important issue for both basic ecological research and predictive biodiversity modelling. However, modelling studies of species richness–remotely sensed productivity estimates relationships (for example Gould, 2000; Kerr, 2001; Fairbanks and McGwire, 2004; Seto et al., 2004) have paid very little attention to the quality of the surrounding landscape (Debinski et al., 2001; Fahrig, 2001). This is a shortcoming because recent studies have shown that local plant species richness can indeed be influenced by landscape ecological factors (Weibull et al., 2003; Marini et al., 2007; Raatikainen et al., 2009).

Here we aim at evaluating the potentiality and relative contributions of local and landscape level greenness estimates, particularly NDVI values, in modelling plant species richness patterns. In the models we used remotely sensed data and geo-referenced floristic records in 440 grid cells of 25 ha in size, gathered from a study area situated in a boreal forest landscape in northern Finland.

Generalized additive models (GAMs) were fitted using three different sets of explanatory variables: (1) local greenness only, (2) landscape greenness only, and (3) combined local and landscape greenness.

In the analysis, we deliberately modelled the species richness in the 28 plant families separately instead of using the overall total species richness. The first reason for so doing was that this allowed us to investigate whether certain plant families are more intimately related to NDVI-based predictors than others. Second, comparisons of richness–productivity relationships reported in different studies may be confounded because of significant methodological and analytical difficulties (Whittaker and Heegaard, 2003). Here, by using plant family richness data we were able to control for consistency in the methodological similarity of analysis and also to provide multiple analyses of species richness–productivity relationships and their form.

2. Materials and methods

2.1. Study area

The study was carried out in Oulanka National Park in northern Finland (66°22'N, 29°19'E) (Fig. 1), which is located near the southern edge of the northern boreal forest zone (for example Parviainen et al., 2008). The northern part of the park is characterised by large treeless wetlands, whereas in the southern part forested hills, and a mosaic of river valleys, water bodies and open wetlands are typical. The vegetation is relatively rich with Arctic, eastern, Siberian and southern species (Vasari et al., 1996), and with Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birches (*Betula* spp.) as the dominant tree species. The mean annual temperature is ca. 0.5 °C, the growing season lasts 128 days and the difference between the mean temperature of the coldest (January, ca. –14 °C) and the warmest (July, ca. 15 °C) month is ca. 29 °C (Atlas of Finland, 1987). The climate in the region is more continental than in most other parts of northern Europe but with a maritime (humid) element added. Topography varies conspicuously and elevation ranges from 140 to 440 m a.s.l.

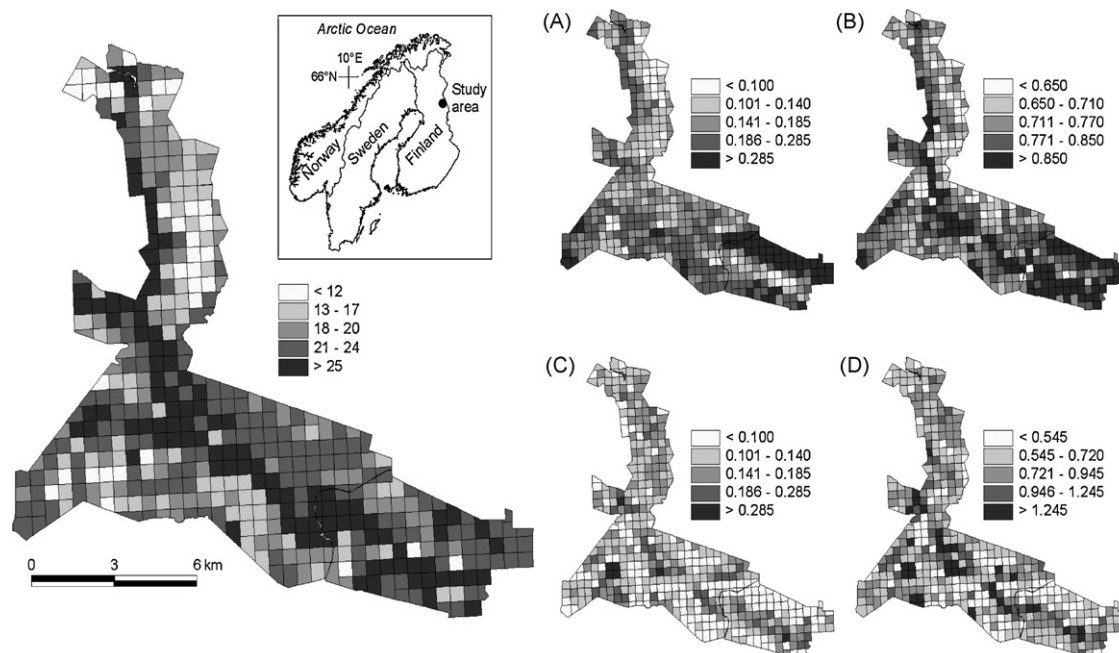


Fig. 1. A map of the richness of plant families in each of the 25 ha grid cells in the study area. The total number of families was 28. Explanatory variables calculated for each of the 25 ha grid cells: (A) mean NDVI, (B) maximum NDVI, (C) standard deviation of NDVI and (D) range of NDVI.

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