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Predictive modelling of protected habitats in riparian areas from catchment characteristics

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ABSTRACT

Wetland habitats are among the most threatened of all ecosystems today and still face an on-going threat despite several international agreements and national policies. In Europe, the Habitats Directive (HD) plays an important role in the protection of habitats and species of European importance. In the present study we use statistical modelling techniques and geographic information systems to explore linkages between HD Annex 1 listed habitats in wetlands and catchment characteristics, e.g. size, geology and land uses at various spatial scales (50 m, 100 m, 500 m and whole catchment). Specifically we test if we can predict the spatial distribution of protected wetland habitats from catchment characteristics and additionally that we can identify critical variables and their spatial scale. We find that we are able to use catchment characteristics to predict the occurrence of protected habitats in riparian areas with 76% correctly classified habitats. At the catchment scale a low percentage of anthropogenic drainage together with a high percentage of forest increase the probability of having protected habitats in riparian areas, whereas at the local scale a low percentage of arable land and a high percentage of natural vegetation increase the probability of having protected habitats. We believe that the model approach used can have important implications. Firstly, the model can be used as a screening tool for identifying areas with potential conservation value. Secondly, the model can also be used as a management planning tool. Riparian areas are increasingly being used as mitigation measures to reduce loads of nutrients and toxic compounds to freshwater ecosystems. These measures may interfere with the hydrological and biochemical settings in riparian areas and threaten communities that are sensitive to eutrophication, e.g. HD Annex 1 habitats. The model can with a relatively high predictability point to areas where mitigation measures should be avoided because of conservation interests. Similarly the model can be used to identify areas that potentially can be restored successfully.

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1. Introduction

The area of wetlands has declined markedly during the last two centuries, and the loss exceeds 50% of the area of peatlands, depressional wetlands, riparian zones and floodplains in North America, Europe and Australia (Millennium Ecosystems Assessment, 2005) mainly due to expanding agricultural, industrial and residential developments. Furthermore flood control programs and waterway commerce have greatly modified existing riparian wetlands largely through the direct alteration of stream channels, e.g. dam construction, flow regulation, channelization and levy construction (e.g. Brookes, 1987; Brookes and Long, 1990; Mattingly et al., 1993; Verdonschot and Nijboer, 2002). This has resulted in draining of wetlands, lower regional groundwater tables, cut off oxbows and meanders, clearing of forests and increased erosion, sedimentation and channel maintenance with major impacts on natural wetland habitats (Mensing et al., 1998; Van Diggelen et al., 2006; Tousignant et al., 2010).

Although ecosystem services of wetlands including biodiversity support are widely appreciated wetlands remain among the most threatened of all ecosystems (Keddy et al., 2009) and still face an on-going threat despite several international agreements and national policies, e.g. *The Ramsar List of Wetlands of International Importance* and *The Convention on Biological Diversity*. In Europe, the Habitats Directive (HD; more formally known as Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora) plays an important role in the protection of biodiversity of European importance. The HD requires EC Member States to introduce a range of measures for the protection of habitats and species listed in its Annexes including over 1000 animals and plant

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species and over 200 habitat types (e.g. special types of forests, meadows, wetlands, etc.). Several wetland habitats are included in the Annex 1 of the HD including oligotropic to mesotrophic standing water habitats being permanent or temporary, groundwater associated habitats, where the water level is at or near the surface of the ground and habitats where surface water flooding is frequent.

In the present study we use statistical modelling techniques and geographic information systems to explore linkages between Annex 1 listed habitats in wetlands and catchment characteristics, e.g. size, geology and land uses at various spatial scales (50 m, 100 m, 500 m and whole catchment). A model that can predict the spatial distribution of wetland habitats may give insight into underlying processes affecting the distribution of protected habitats and serve as a basis for the design of survey, research, and conservation strategies. Furthermore such a model can be used to identify potential areas of conflict between conservation interests and other uses of wetland services, e.g. the use of wetlands for water quality improvement (e.g. Hill, 1996; Venterink et al., 2006) or agricultural developments. The rationale behind this approach is that catchment processes either directly or indirectly affect habitat conditions in riparian areas (see Mander et al., 2000; Jansson et al., 2007; Carreño et al., 2008; Schmalz et al., 2009; Klimkowska et al., 2010; Tousignant et al., 2010). For example large-scale anthropogenic drainage and groundwater abstraction reduce the groundwater flow to wetlands (e.g. Van Diggelen et al., 2006). It may also affect the relative importance of regional and local groundwater, precipitation water and surface water in the areas (Toth, 1999; Grootjans et al., 2006; Dahl et al., 2007) and flow patterns within the areas (Van Loon et al., 2009; Klimkowska et al., 2010). The quality of the water that reaches the wetlands may link to agricultural production in the catchment (Allan et al., 1997; Ekholm et al., 2000; Ferrier et al., 2001; Davies and Neal, 2007) and agricultural management (Andersen et al., 1999, 2005; Vagstad et al., 2004) directly or indirectly by flooding thereby affecting riparian habitats. Specifically we test if we can predict the spatial distribution of protected wetland habitats from catchment characteristics reflecting that human activities in the catchment has implications even when conducted at large distances from an area and additionally that we can identify critical abiotic variables and their spatial scale. We use an extensive dataset covering >20,000 plots situated in >400 different riparian areas distributed throughout Denmark to test these hypotheses. We use the term riparian area as we acknowledge that the term wetland is inappropriate in many places because of drainage either locally or in the catchment. The areas integrated in the study are representative of riparian areas in Denmark that are not in use for agricultural production (crops and grassland) and cover culturally improved meadows and pastures and Annex 1 listed habitats of HD.

2. Methods

2.1. Study sites and sampling

Vegetation surveys were carried out in 2004 and 2005 in a total of 454 riparian areas with semi-natural grassland vegetation and scattered occurrence of trees. The areas were delimited by a 100 m long stream section reaching 30 m into the riparian area. The areas were randomly distributed throughout Denmark excluding areas with agricultural production (crop and grass) as well as areas with dense tree cover (very rare in Denmark). Surveys were performed in a total of 21,401 plots each being 10 m × 10 m (Pedersen et al., 2007). In each plot a cover score value was allocated to plant species using the following scale: 1: <0.5%; 2: 0.5–1%; 3: 1–2.5%; 4: 2.5–5%; 5: 5–12.5%; 6: 12.5–25%; 7: 25–50%; 8: 50–75%; 9: >75%.

Vegetation data were translated into habitat types using a species-based classification model for semi-natural and natural riparian vegetation (Nygaard et al., 2009). The model was developed to achieve a statistical and standardised interpretation of habitat types in Denmark and builds on 13,000 plots and a total of 700 species covering a gradient in human impact ranging from natural habitats with semi-natural vegetation (e.g. mires and flushes) to culturally improved meadows and pastures. The model comprises Annex 1 habitats of the EU Habitats Directive and is in accordance with the *Interpretation Manual of European Union Habitats* (EUR 27, 2007). Habitats not listed in the Annex 1 of the HD are, similarly to the Annex 1 habitats based on CORINE (Devillers et al., 1991). CORINE lists biotopes or broad habitats, which are differentiated by the growth form of the vegetation and ecosystem functions.

The Ellenberg index is a comprehensive indicator system describing the response of species to a range of abiotic conditions (Ellenberg, 1979; Ellenberg et al., 1991). Ellenberg N indices were used to assess productivity level of the community and moisture preference. Weighted means of Ellenberg N and Ellenberg F were calculated for each of the 21,401 plots, scoring from 1 to 9, i.e. low to high preference for nutrients/moisture.

2.2. Abiotic variables

The total set of abiotic variables include soil parent material, land cover, anthropogenic drainage, low-lying hydromorphic areas, and the nitrogen field balance for agricultural land. For all riparian areas the catchment was delineated from elevation contours on a national digital topographic map 1: 25,000 (Nielsen et al., 2000). All variables were scored at five scales: (i) the total catchment upstream of the stream reach; (ii) a 500 m wide buffer along upstream stream reaches in the catchment; (iii) a 100 m wide buffer along upstream stream reaches in the catchment; (iv) a 50 m wide buffer along upstream stream reaches in the catchment; and (v) an approximately 100 m × 100 m section located immediately upstream the riparian site. The different buffer zones and the 100 m × 100 m upstream sections were determined using the Analysis Tools in ESRI ArcGIS 9.2.

Soil parent material was determined from a digital national geological map in 1:200,000 (GEUS, 2008). Soil parent material was scored at all five scales as percentage coverage of main classes: clay, silt, sand, gravel, peat, chalk, and pre-quaternary deposits.

In order to determine land cover two sources of digital land cover data were combined: a national land cover raster map (25 m grid) with 12 land cover classes (Nielsen et al., 2000) and information on land use mandatory reported by all farmers annually to the Danish Ministry of Agriculture as a requirement for obtaining EU subsidies (DFFE, 2008). This latter source contains information on field location and crop type. Land cover polygons were reclassified as arable land, permanent grass, forest, natural dryland vegetation such as grassland and heath and natural wetland vegetation such as fens and meadows, lakes, streams and impervious surfaces.

The extent of anthropogenic drainage was approximated from a new digital 250 m grid map showing the need for drainage (Greve, 2008a) determined by combining soil types in top soil and sub soil with landscape types and relating to surveys of need for drainage of agricultural land. It was assumed that a high potential need for anthropogenic drainage is equivalent to a high extent of actual anthropogenic drainage. Low-lying hydromorphic areas existing around year 1900 have been digitized from old maps in 1:20,000 (Greve, 2008b). Many of these areas are anthropogenic drained and used for agricultural production.

The nitrogen field balance for agricultural areas was determined from annual mandatory reports by all farmers to the Danish Ministry of Agriculture (DFFE, 2008). These reports contain data on

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