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Mapping to inform conservation: A case study of changes in semi-natural habitats and their connectivity over 70 years

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ABSTRACT

Intensification of human activities has caused drastic losses in semi-natural habitats, resulting as well in declining connectivity between remaining fragments. Successful future restoration should therefore increase both habitat area and connectivity. The first steps in a framework for doing so are addressed here, which involve the mapping of past habitat change. We present a method which is unique in: the large area covered (2500 km^2), the high resolution of the data (25 × 25 m), the long period assessed (70 years), and a system for translation of land use maps into Broad Habitat Types using soil surveys.

We digitised land use maps from the 1930s for the county of Dorset in southern England. The resulting map was compared to the UK Land Cover Map of 2000. For our example area, land use shifted dramatically to more intensive agriculture: 97% of all semi-natural grasslands were converted into agriculturally-improved grassland or arable land as were large proportions of the heathlands and rough grasslands (−57%). The other important driver of change was afforestation (+25%). The larger habitat areas became fragmented, with average fragment size of different habitats falling by 31–94%. Furthermore, the connectivity between fragments dropped drastically, by up to 98%.

Analyses such as those presented here not only quantify the scale and pattern of habitat loss, but are important to inform land-use planning to restore biodiversity by both increasing the available habitat and facilitating dispersal among habitat fragments. We discuss the possible steps for such a framework.

1. Introduction

During the second half of the 20th century, the Western European landscape became more intensively used, affecting especially semi-natural habitats which are the principal hotspots for biodiversity (Benton et al., 2003; Fuller, 1987; Henle et al., 2008). In particular, rural areas were altered dramatically in the pursuit of increased production, reflecting a higher demand for food and feed by a growing human population (“intensification”). Many previously low productivity areas were reclaimed, drained and/or fertilised for grass production or converted to arable land (Fuller, 1987; Hodgson et al., 2005; Swetnam, 2007). Further severe losses of habitat were caused by urbanisation and building (Feranec et al., 2010; Gerard et al., 2010; Thomson et al., 2007), as well as afforestation for timber production (Mason, 2007). In addition to severe declines in the area of such habitats, these processes decreased the connectivity of remaining fragments, which became more isolated (Fahrig, 2003; Stoate et al., 2001). Decreased connectivity reduces dispersal among plant and animal populations (Soons et al., 2005), leading to an elevated extinction risk at population and regional scales (Fahrig, 2003; Keller and Waller, 2002).

While loss of semi-natural habitats continues (Feranec et al., 2010; Howard et al., 2003; UK National Ecosystem Assessment, 2011), many restoration efforts are taking place (Lawton et al., 2010; Wade et al., 2008). Successful future restoration of semi-natural habitat not only requires selection of sites which are amenable for restoration to the target habitat (Walker et al., 2004), but should ideally also aim to enhance habitat connectivity (Brudvig, 2011; Bullock et al., 2002). Despite increasing interest in the restoration of such “ecological networks” (Lawton et al., 2010), the process is not straightforward. The necessary first step is to map the long-term changes in habitat cover in a region, on an as fine a scale as possible. Such maps will give baseline information on earlier habitat configurations and will allow planning of ecological networks based on ease of restoration (Jackson and Hobbs, 2009; Wade et al., 2008), and increasing connectivity of a variety of habitat types (Guisan and Zimmerman, 2000).

We report here on a habitat mapping project covering an area of ca. 2500 km^2 at the detailed resolution of 25 × 25 m, and comprising over 4-million data-points. We compared land use in the 1930s with that in 2000. The 1930s maps represent the period before the massive intensification of land use in the UK after World War II, and can be taken as an “ideal” situation for semi-natural habitats,

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such as heathlands and low productivity grasslands, and the species inhabiting them (UK National Ecosystem Assessment, 2011). Previous studies using map and vegetation survey data indicate a very large loss of semi-natural habitat over the last 75 years (Fuller, 1987; Hodgson et al., 2005). However, while researchers have produced maps of loss of particular habitat types over long timescales (e.g. heathlands; Webb and Haskins, 1980; Webb, 1990) or whole landscape changes over shorter, more recent, periods (e.g. Burnside et al., 2003), little has been done to determine overall patterns of habitat change for whole socio-political regions over long periods.

One problem in mapping land cover change, especially over long intervals, is the difficulty of matching land cover types between different surveys (Dallimer et al., 2009). Here, we overcome this difficulty by matching maps according to habitat types. We utilise the first Land Utilisation Survey done in the UK in the 1930s (Stamp, 1931) and after digitising these maps, combine them with soil maps to derive a habitat classification. The Dudley Stamp maps are unique in their level of detail, being an early example of volunteer recording. Only 10% is available of the second Land Utilization Survey in the 1960s and so subsequent detailed maps are not available until the UK Land Cover Map in 1990 (Fuller et al., 1994). In this study we use the UK Land Cover Map of 2000 (LCM2000), and develop a method to make the habitat types of the Dudley Stamp maps comparable to the Broad Habitat Types of the LCM2000 as described in Fuller et al. (2002a, 2002b).

The model study area of Dorset, a county bordering the south coast of England, is a prime example of a pre-dominantly rural region which underwent rapid, but with gradual speed, intensification during the mid to late 20th century (Keymer and Leach, 1990; Webb and Haskins, 1980). Dorset, however, was and remains a major UK biodiversity hotspot (Prendergast and Eversham, 1995; Preston et al., 2002; Williams et al., 1996), which indicates the potential for positive responses to the restoration of ecological networks.

In this paper we report on a habitat change mapping project using Dorset as a case study and present habitat maps for the 1930s and 2000. The objectives include (i) a test of the accuracy of the constructed 1930s habitat map using contemporaneous, but independent vegetation surveys. We then investigate the changes in semi-natural habitats that occurred between the 1930s and 2000 and their apparent drivers in terms of: (ii) the total available habitat; (iii) the size of fragments of semi-natural habitat types; and (iv) the connectivity among fragments. We discuss the use such mapping efforts as a first step in developing plans for ecological network restoration.

2. Material and methods

2.1. Example area and maps

The county of Dorset on the south coast of England is currently 2653 km^2 in area, but, because of boundary changes, was ca. 2500 km^2 in the 1930s. Dorset's population roughly doubled between 1931 and 2001 from ca. 198,000 to ca. 391,000 inhabitants, excluding the urban centres of Poole and Bournemouth (Southall et al., 2010). More importantly, the county is a diversity hotspot for species and habitats. The "New Atlas of the British and Irish Flora" shows that the most species-rich 100 km^2 square lies in Dorset (1107 vascular plant species: Preston et al., 2002). Dorset also contains some of the 5% most species-rich 100 km^2 squares in Britain for butterflies (Prendergast and Eversham, 1995), birds (Williams et al., 1996) and freshwater plants and invertebrates (Palmer, 1999). About 9% (223 km^2) of the terrestrial area comprises EU Natura 2000 sites (Natura 2000, 2011).

2.1.1. 1930s habitat map

The First Land Utilisation Survey of Great Britain was accomplished during the 1930s (Stamp, 1931). Volunteers recorded land uses onto the 1904 UK Ordnance Survey maps (1:10,560) between 1931 and 1934 (Southall et al., 2007). The merging of those maps into one-inch-to-the-mile sheets (1:63,360) created the "Dudley Stamp maps" (DSM). The main land-use categories were: (i) Forest and woodland; (ii) Arable land; (iii) Meadowland and permanent grassland – which we will call "managed grasslands"; (iv) Heaths, moorlands, commons and rough hill pasture – using soil data we will split these into "heaths" and the "rough grasslands" (see next paragraph); (v) Gardens, including allotments, orchards and nurseries; (vi) Agriculturally unproductive land, which included buildings, mines, railways and suchlike; (vii) Inland water and sea; and (viii) Littoral features, shingles and saltmarshes.

The maps have been scanned and can be viewed on-line (Southall et al., 2010). We manually digitised six of the 300 dpi scanned DSMs (sheets 121, 129, 130, 131, 140 and 141), which encompassed Dorset. These map sheets had been previously georeferenced to the Ordnance Survey of Great Britain 1936 national grid (OSGB-36) (Fuller et al., 2002a). Digitisation was done in Adobe Photoshop, identifying features as small as 2×2 pixels (10.8×10.8 m). The six resulting maps were imported into ArcGIS 9.3 and the eight land-use categories were vectorised into a GIS-layer. Subsequently, these maps were combined with the 1:250,000 vector-based National Soil Map of England and Wales (Thompson, 2007), using the 27 soil map units of the Soilscape format. The resulting Soilscape $\times$ DSM land use matrix was then translated into 15 Broad Habitat Types (BHT; Supplementary Materials Table S1; Fig. 1), which were compatible with the BHTs of the Land Cover Map described in Section 2.1.2. In this way, we separated neutral, calcareous and acid grasslands into "managed" (DSM category iii) and "rough" (DSM category iv, excluding heaths). "Rough grassland" is used in the Land Cover Map to describe the tall, tussocky and scrubby grassland resulting from minimal management, and Stamp (1931) used a similar criterion to distinguish "moorlands, commons and rough hill pasture". For simplicity, we refer to the resulting habitat map (Fig. 1a) as the Dudley Stamp map (DSM).

The DSM does not include an agriculturally-improved grassland category. However, there is evidence that almost all English grasslands at that time were unimproved, in the sense that they were not receiving inorganic fertilisers (Fuller, 1987). We confirmed the low cover of improved grassland in 1930s Dorset using the Good vegetation survey data, which we describe in Section 2.3, in the context of validating the DSM. A best fit National Vegetation Classification (NVC) category (Rodwell, 1992) was assigned to each of Good's grassland survey sites using Tablefit (Hill, 1996). Of the 2163 grassland survey sites, all corresponded best to NVC unimproved grassland categories, except nine which were classified as MG7 (*Lolium perenne* leys) and 42 as MG6 (*Lolium perenne* – *Cynosurus cristatus* grassland), indicating only 2.3% of grasslands were possibly improved.

2.1.2. Land Cover Map 2000

To indicate habitat coverage in 2000 we used the Land Cover Map 2000 (LCM2000), which is the definitive land cover map for the UK, and has been widely used in conservation research (e.g., Oliver et al., 2009). The LCM2000 is derived from satellite spectral data (Fuller et al., 2002b) in which assignments of 25×25 m pixels to BHTs used a maximum likelihood algorithm (Fuller et al., 2002a). The minimum parcel size is 8 pixels (5000 m^2). These pixels were converted into a vectorised GIS layer. Semi-natural grasslands were divided into acidity categories using an acid-sensitivity projection, with a pH threshold of 4.5 for acid grasslands. We refer to Fuller et al. (2002a, 2002b) for technical