Journal of Environmental Management 196 (2017) 692–701

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

How hedge woody species diversity and habitat change is a function of land use history and recent management in a European agricultural landscape

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ARTICLE INFO

Article history:
Received 7 September 2016
Received in revised form
15 March 2017
Accepted 21 March 2017
Available online 31 March 2017

Keywords:
Hedge
Woody species
Species diversity
Introduced species
Ecosystem services
Landscape history

ABSTRACT

European hedged agricultural landscapes provide a range of ecosystem services and are an important component of cultural and biodiversity heritage. This paper investigates the extent of hedges, their woody species diversity (including the influence of historical versus recent hedge origin) and dynamics of change. The rationale is to contribute to an ecological basis for hedge habitat management. Sample sites were allocated based on a multivariate classification of landscape attributes. All field boundaries present in each site were mapped and surveyed in 1998 and 2007. To assess diversity, a list of all woody species was recorded in one standard 30 m linear plot within each hedge. There was a net decrease in hedge habitat extent, mainly as a result of removal, and changes between hedges and other field boundary types due to the development and loss of shrub growth-form. Agricultural intensification, increased rural building, and variation in hedge management practices were the main drivers of change. Hedges surveyed at baseline, which were lost at resurvey, were more species rich than new hedges gained. Hedges coinciding with historical land unit boundaries of likely Early Medieval origin were found to be more species rich. The most frequent woody species in hedges were native, including a high proportion with *Fraxinus excelsior*, a species under threat from current and emerging plant pests and pathogens. Introduced species were present in circa 30% of hedges. We conclude that since hedge habitat distribution and woody species diversity is a function of ecology and anthropogenic factors, the management of hedges in enclosed agricultural landscapes requires an integrated approach.

1. Introduction

Hedges, usually defined as narrow woody linear features composed of woody species with shrubby growth forms, are one of the main types of field boundary in enclosed agricultural landscapes within Europe. Hedged agricultural landscapes, generally referred to as *bocage*, occur throughout Western Europe (Baudry et al., 2000), notably around the Atlantic fringe, in France and Galicia (north-west Spain). Hedges form a dense network throughout Ireland (Aalen et al., 1997), and are widespread in Britain (Rackham, 1997).

Hedges have originated mainly due to planting, but also by spontaneous natural colonisation of woody species along other field boundary and linear feature types, and occasionally as remnants, e.g. along an ownership boundary, left after the process of woodland assarting (clearance) for agricultural land (Forman and Baudry, 1984; Pollard et al., 1974; Rackham, 1997). While historically the main function of hedges was for agricultural land enclosure, they were usually managed as a source of wood for fuel and crafts, and for natural foodstuffs.

Enclosed agricultural landscapes can deliver multiple ecosystem services (e.g. Firbank et al., 2013) and are acknowledged as part of the European cultural and biodiversity heritage, (EEA, 2010); hedges, as characteristic components, are also recognised for their contribution to spatial connectivity and green infrastructure. Hedges have an ecological role and provide a range of ecosystem services to which their woody species diversity and associated linear features such as banks, ditches and verges, contribute (see Table S.1).

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http://dx.doi.org/10.1016/j.jenvman.2017.03.066
0301-4797/

1.1. Plant species diversity in hedges

The flora of the hedge ground layer, and associated linear features, can contain a wide range of plant species (Critchley et al., 2013), although this can be largely affected by the adjacent land use and its management (Cherrill et al., 2001; Ernoult and Alard, 2011; French and Cummins, 2001), and can also be due to age (Deckers et al., 2005; Pollard et al., 1974). Due to their linear structure and limited width, hedges are typically characterised by a high edge to area ratio and thus consist mainly of edge habitat, and may act as habitat for woodland edge ground flora (Closset-Kopp et al., 2016; McCollin et al., 2000). Species-richness has been found to be greater in "green lanes", i.e. two parallel hedges separated by an unmetalled (non-sealed) track (Walker et al., 2006); sunken types notably support woodland species (Deckers et al., 2005). Ditches associated with hedges may contain wetland species of habitats such as fen, swamp and reedbeds (Herzon and Helenius, 2008). Field margin strips associated with hedge verges which are managed specifically to provide benefits for wildlife, can contribute to biodiversity where arable crops are grown (Marshall and Moonen, 2002). Epiphyte communities (lichens, mosses, liverworts, algae), exploit the surfaces of bark, wood and leaves (Alexander et al., 2006).

The woody species composition of hedges is a major source of vascular plant biodiversity in agricultural landscapes, especially where other habitats such as woodland and scrub may be scarce. It has been proposed that hedges accumulate woody species over time (c. 1 per 100 year), assuming a baseline stock of one species in a standard thirty yard (27.4 m) length of hedge, Hooper's Rule (Hooper, 1970; Pollard et al., 1974). Developed in parts of England, this relationship has been postulated as a method for dating hedges. Studies in Ireland (Condon and Jarvis, 1989; Doogue and Kelly, 2006; Synnott, 1973), and elsewhere in England (Cousins, 2004; Willmot, 1980), have critically assessed the application of the rule in other locations. Woody species richness may also depend on hedge origin, i.e. spontaneous, remnant or through planting with single or mixed species. When this is unknown, Hooper's Rule may be used as a rough indicator of hedge antiquity (Barnes and Williamson, 2006; Edwards et al., 2006). One outcome of the rule is that a standard linear plot of length 30 m is now used as the basis for assessing hedge woody species diversity.

1.2. Threats to hedge habitat extent and woody species diversity

Field boundary removal as a result of agricultural intensification and increasing mechanization within Europe in the latter part of the 20th Century, was the main threat to hedge habitat conservation and ecosystem services function, and to landscape structure, e.g. in Ireland (Cooper et al., 2002; Murray et al., 1992), Britain (Petit et al., 2003), and in France (Pointereau, 2001). More recently, compliance regulations specifying that farmers must follow statutory management requirements in order to qualify for full farm subsidy payments under the EU Common Agricultural Policy (CAP), and the introduction of agri-environment schemes (AES), has resulted in a decline in the rate of hedge loss (Carey et al., 2008; Norton et al., 2012), with the main threat being identified as lack of hedge maintenance.

A range of current and emerging invasive non-native pests and diseases threaten native tree and shrub species composition in hedges. A recent example is ash (*Fraxinus excelsior*) dieback disease caused by the fungal pathogen *Chalara fraxinea* (anamorph) and *Hymenoscyphus pseudoalbidus* (teleomorph), while the emerald ash borer beetle *Agrilus planipennis*, a serious pest of ash species in North America, is also emerging as a severe threat to ash in Europe (Mitchell et al., 2014; Thomas, 2016). Native woody species in hedges may also face competition from alien introductions. While there has been a history of non-native plant species introduction to Ireland (Reynolds, 2002), there has been no systematic ecological study of the extent, distribution and frequency of introduced woody species in hedge habitats of the rural landscape.

1.3. Aims

This paper assesses the woody species diversity (richness and composition) of hedges in a European enclosed agricultural landscape. We investigate recent changes in the extent of hedge habitat, the dynamics of hedge loss and gain, and associated changes in woody species diversity. The diversity of hedges established by historical and recent territorial land organisation is also compared. The rationale is to contribute to an ecological basis for hedge habitat conservation and management within the context of rural land use.

2. Methods

2.1. Study area

The study area was Northern Ireland (NI), Fig. 1. NI has a mid-latitude western European location with an oceanic climate. The planar area, measured to the high water mark of medium tides in coastal locations, is 14,160 km^2. Circa 68% (9676 km^2) of the landscape is lowland, i.e. less than 150 m elevation. Gleyed soils are widely distributed (Cruickshank, 1997). The upland landscape, which is mostly below 300 m, includes extensive cover of blanket peat. Agriculture is largely grass-based (DARD, 2007) and is concentrated in the lowlands and marginal uplands. Agricultural grassland and crops total 8452 km^2 and make up circa 62% of the land area.

2.1.1. Sampling programme

A sampling programme was set up to estimate the extent of terrestrial habitats and field boundaries and to monitor change in NI on behalf of the Environment Agency (Cooper et al., 2002, 2009; McCann et al., 2009). Sample sites (size 500 m × 500 m, $n = 287$), each of which was located within an Ordnance Survey Irish grid 1 km square (Fig. 1), were allocated by stratified random sampling based on a multivariate classification of map attributes such as elevation, slope, soils and geology (Cooper, 1986), to represent landscape structure. The sampling fraction was 0.5%, i.e. the total area of the sites as a percentage of the total landscape area (excluding a large waterbody area, mainly Lough Neagh, which was treated as a constant).

2.1.2. Hedge habitat survey

Field boundary survey was carried out in summer 1998 (baseline) and repeated in 2007 (resurvey), using the sample sites. Within each site, all field boundaries present were mapped and surveyed, except for those boundaries within curtilage (i.e. gardens and land associated with urban areas, farm or domestic buildings) and within woodland. The scale of resolution for field boundary mapping was a minimum mapping length of 20 m. Individual field boundary end-points were usually the intersections with other field boundaries (McCann et al., 2009), see Fig. S.1.

Hedges were defined as linear features (<5 m wide) composed of woody species with a shrubby growth form (either natural or induced by management), covering more than 25% of the boundary length (McCann et al., 2009). Woody species nomenclature followed Webb et al. (1996) and Stace (1997). Woody species not classed as hedge-forming, were the shrubs *Ulex europaeus* and *Cytisus scoparius*, climbers–scramblers such as *Hedera helix*,