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A graph-based approach to defend agro-ecological systems against water vole outbreaks

Jean-Christophe Foltête[a,*], Geoffroy Couval[b,c], Marilyne Fontanier[c], Gilles Vuidel[a], Patrick Giraudoux[b]

[a] *ThéMA, UMR 6049 CNRS, Université Bourgogne-Franche-Comté 32, rue Mégevand F-25030 Besançon, France*
[b] *Chrono-Environnement, UMR 6249 CNRS, Université Bourgogne-Franche-Comté, 16 route de Gray, F-25030 Besançon cedex, France*
[c] *FREDON Franche-Comté Espace Valentin Est, 12 rue de Franche-Comté, F-25480 Ecole-Valentin, France*

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ABSTRACT

The cyclic spread of montane water vole populations in the grasslands of the Jura plateaus causes severe economic, ecological, and public-health problems. Since this phenomenon cannot be managed by massive use of the anticoagulant rodenticide bromadiolone, the challenge is to limit it by reducing regional-level connectivity through landscaping and agro-environmental interventions such as planting hedgerows, ploughing, and cultivating cereals. We used landscape graphs – a spatial modelling approach based on graph theory – to represent the grassland network and identify key areas for intervention. Several strategies were compared in terms of their capacity to fulfil operational requirements by interchanging patches and meta-patches as nodes of the graph, and least-cost distances and resistance distances to weight links. The combination of meta-patches and resistance distances provides a relevant basis on which to design concrete action to decrease regional-level connectivity of grasslands. The results also indicate that the usual removal method applied to the links of the graph would benefit from data on the statistical distribution of cost values along the shortest paths. More broadly, this suggests the modelling approach should be better matched the actual field interventions if the connectivity analysis is to be operational.

1. Introduction

Montane water vole (*Arvicola terrestris sherman*) populations on the Jura plateaus (eastern France) spread in five- to eight-year cycles involving four successive phases: low density, population growth, high density, and population decline (Blant et al., 2009; Giraudoux et al., 1997). This grassland rodent feeds mostly on plant roots and expels earth on the ground surface from its shallow tunnels. Montane water vole population outbreaks do considerable floristic (Delattre and Giraudoux, 2009) and economic damage (Quéré et al., 1999), and pose a public-health problem because the species is a reservoir for agents of human diseases such as alveolar echinococcosis (Viel et al., 1999).

Numerous studies have already been carried out on several spatial scales into the factors explaining montane water vole population proliferation in the Jura Mountains. On a scale of approximately 25 km^2, landscape composition dominated by grassland is amenable to outbreaks (Giraudoux et al., 1997). The identification of genetic clusters indicates that major valleys with rocky cliffs form diffusion barriers (Berthier et al., 2005, 2014). Locally, propagation rates vary with the landscape context, being more intensive and more rapid in homogeneous grassland openfields than in heterogeneous mosaics of grasslands, hedgerows, and wooded patches (Duhamel et al., 2000; Berthier et al., 2009; Foltête et al., 2008; Morilhat et al., 2007, 2008). All of those studies underscore the importance of connectivity among grassland areas for population diffusion.

The fight against the spread of water vole outbreaks usually involves bromadiolone, an anticoagulant rodenticide, as part of a toolbox including a combination of other complementary methods such as soil disturbance, cattle tramping, and mole control in source areas (Michelin et al., 2014). However, bromadiolone has been shown to have a negative impact on other non-target wildlife species (common buzzard, red kite, fox, wild boar) and ultimately proves ineffective on more than a local scale (Delattre and Giraudoux, 2009; Coeurdassier et al., 2014). Consequently, it is important to try to limit the spread of montane water vole popu-

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* Corresponding author.
E-mail addresses: jean-christophe.foltete@univ-fcomte.fr (J.-C. Foltête), gcouval@fredonfc.com (G. Couval), m.fontanier@fredonfc.com (M. Fontanier), gilles.vuidel@univ-fcomte.fr (G. Vuidel), patrick.giraudoux@univ-fcomte.fr (P. Giraudoux).

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lations by reducing regional-level connectivity through landscape planning and agro-ecological interventions. The question, then, is how best to identify the most suitable locations for such actions. As the focus is on functional connectivity of grasslands, this paper sets out to define a methodological framework capable of providing a decision-support tool.

Several methods are used to quantify connectivity in landscape ecology, especially individual-based movement models (Grimm and Railsback, 2005), least-cost analyses (Adriaensen et al., 2003), circuit theory (Carroll et al., 2011; McRae et al., 2008), centrality analyses (Rudnick et al., 2012), and landscape graphs (Urban et al., 2009). Following Calabrese and Fagan (2004), graph-theoretical methods provide an interesting trade-off for characterizing ecological processes from a small amount of input data and adjustments. The main purpose of these methods is to answer practical questions about spatial planning and biological conservation. They are used in particular for determining priorities among areas to be protected or restored (Saura and Pascual-Hortal, 2007), improving connectivity, or reducing the effect of disruptive developments (Clauzel et al., 2015; Foltête et al., 2014). Landscape graphs are widely used to preserve or improve connectivity; here we reverse the approach and attempt to identify vulnerable areas in the grassland network where planning measures or direct actions are likely to be most effective in decreasing regional-level connectivity of grasslands.

Landscape graphs are valuable in providing a decision support, but despite their relative simplicity, applying them involves making critical choices about the basic components of the graphs. Among these choices, that concerning the type of distance, the definition of the resistance maps and the large range of connectivity metrics are well-known from several reviews and comparisons (Baranyi et al., 2011; Laita et al., 2011; Rayfield et al., 2011; Szabó et al., 2012; Ziółkowska et al., 2014). But other choices have to be made in defining the basic elements of the graph before a given connectivity metric can be computed. Galpern et al. (2011) list many possibilities for designing patches (nodes) and links depending mainly on the characteristics of the focal species and the context of the study. Recently, Blazquez-Cabrera et al. (2014) have looked into the robustness of connectivity metrics according to the spatial scale at which habitat patches are defined. Comparing several applications of the patch-removal method, those authors report that the assessment of the reduction in connectivity due to patch removal seems to depend heavily on how patches are defined, but conversely the rank of reduction (i.e. the prioritization criterion) is not so sensitive to this definition. In an alternative approach, Avon and Bergès (2016) investigate the impact of the type of distance defining the inter-patch links on patch prioritization. They show that the prioritization of the patches acting as network connectors is sensitive to the type of distance, but this impact is not observed for patches acting as sources of dispersal flux. While these studies provided new findings on the behaviour of graph elements (i.e. patches and links), the operational use of landscape graphs requires a better understanding of the ways in which the definition of these elements may impact their capacity to provide results that cater for real needs in terms of landscape management or agricultural practices.

The aim of this paper is to use landscape graphs to locate, prioritize, and finally apply agro-ecological interventions against montane water vole population spread in the French part of the Jura Massif. A previous graph-based analysis was conducted in the same study area to evaluate the relevance of landscape graphs in the case of cyclic population fluctuations and to find suitable settings for the modelling approach (Foltête and Giraudoux, 2012). With the aim of limiting connectivity, the search for the most relevant locations for agro-ecological interventions is based on a step-by-step procedure simulating the removal of graph elements, following the same principle as the addition of new elements described in Foltête et al. (2014).

The local impact of agricultural practices such as ploughing on common vole mortality is well-known (Bonnet et al., 2013; Delattre et al., 1992; Jacob and Hempel, 2003; Jug et al., 2008). Here, the final objective is to attempt to decrease regional connectivity in the field, by transforming a limited number of grassland parcels into ploughed fields e.g. for cereal crops (in order to destroy vole galleries), by planting perches for buzzards and other birds of prey, and possibly planting hedgerows to increase the accessibility of avian and mammal predators to vole populations. As this approach is experimental and financially limited, these measures must be focused and implemented locally. Consequently, the action areas likely to be identified from the connectivity analysis must respect criteria of practicality, i.e. these areas must be small and not located in large openfields where a new element likely to obstruct the diffusion of water voles (e.g. ploughed parcel or hedgerows) may be easily bypassed. These constraints led us to consider two main options in the construction of the basic elements of the graphs:

(1) should nodes be defined by grassland patches or grassland meta-patches, i.e. clusters of patches? The concept of meta-patch has been proposed by Zetterberg et al. (2010) to reflect the different scales of ecological processes represented by graphs. Here, we address the question of meta-patches from a practical point of view, assuming that they are more relevant since they avoid selecting among too closely-spaced elements that could be hard to disconnect in the field;
(2) should link impedance be defined as least-cost distances (as in the usual computations) or as resistance distances derived from circuit theory? Resistance distances have been introduced to reflect the potential population fluxes more relevantly than least-cost distances (McRae et al., 2008). Since they can distinguish narrow corridors from wide connection tracts, they are assumed to be more suitable in the present case.

Thus, we propose to compare methodological options for selecting strategic areas likely to reduce regional-level connectivity. This comparison is based on an assessment where the selected areas are additionally evaluated in terms of their capacity to comply with the operational constraints of practicability mentioned above. The best strategy selected led us finally to plan several actions in a key area of the grassland network.

2. Material and methods

2.1. Study area and land cover data

The Jura massif lies on the border between France and Switzerland. Its western part is a series of karst plateaus rising from 400 m in the west to 1000 m in the east. These plateaus are bounded by deep valley gorges and are mostly covered by grassland and forest. In the eastern part, the Folded Jura is characterized by higher relief culminating at 1700 m and landscapes dominated by coniferous forests. The study area extends over 5000 km^2 of the Jura massif (Fig. 1).

Land cover was mapped by combining several data sources. Buildings, the hydrographic network, transport infrastructures, and forests (deciduous, evergreen, and mixed) were extracted from the French land-cover database (BD Topo IGN 2010). Agricultural areas classified into two categories (annual crops and grassland) were taken from a farming database (BD Agreste 2010). Ponds and wetlands were taken from a special-purpose database (BD Zones Humides DREAL). The main hedgerows were identified by "morphological spatial pattern analysis" (Vogt et al., 2007) on the basis of the layer describing forests in BD topo 2010. Ultimately, a map con-