Ecological Modelling 273 (2014) 228–235

Contents lists available at ScienceDirect

Ecological Modelling

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

Integrated modelling of functional and structural connectivity of river corridors for European otter recovery

K. Van Looy[a,*], J. Piffady[a], C. Cavillon[a], T. Tormos[a,b], P. Landry[c], Y. Souchon[a]

[a] National Research Institute of Science and Technology for Environment and Agriculture IRSTEA Lyon, UR MALY, River Hydro-Ecology Unit ONEMA IRSTEA, 5 rue de la Doua, 69626 Villeurbanne, Lyon, France
[b] French National Agency for Water and Aquatic Environments (ONEMA), France
[c] National Wildlife Office (ONCFS), France

ARTICLE INFO

Article history:
Received 24 July 2013
Received in revised form 8 November 2013
Accepted 9 November 2013
Available online 7 December 2013

Keywords:
Dendritic network
Riparian corridor
Dynamic occupancy modelling
Integral index of connectivity
Colonization
Hydromorphology

ABSTRACT

Connectivity may be *structural*, based on adjacency of landscape features, or *functional*, based on how that adjacency translates to movement of organisms. We present a modelling approach that elucidates both aspects of connectivity to identify vital corridors and conservation priorities in a river network. For the dendritic network structure of river systems, at first a graph theoretic structure is developed to model the river network at the segment scale. To derive functional connectivity, a Bayesian hierarchical modelling of species dispersal is applied to infer the influence of riparian corridor characteristics to the species colonization.

The integration of the functional and structural component is realized with a graph-theoretic connectivity measure. With this approach, the European otter colonization of the Loire river basin over 25 years is modelled on the basis of large datasets on riparian corridor land use and hydromorphological characteristics of a 17,000 km river network. Channel straightening and riparian forest fragmentation are determined to be key elements to the functional connectivity. Road infrastructure is distinguished as a critical habitat factor, but not so much an obstacle for the species movement in the riparian corridor. Integration of the Bayesian model posterior colonization probability in the integrated connectivity analysis reveals the importance of the river network density to the otter colonization and locates conservation priorities mainly in the lower parts of the river basin.

Synthesis and applications: Both functional and structural connectivity are essential elements in the contexts of ecological network identification for species conservation and recovery. We successfully developed an integrated modelling of both components of connectivity that highlighted the importance of the downstream basin for a well-connected ecological network for the otter.

1. Introduction

The role of river corridors in providing connectivity is questioned in the context of defining ecological networks over large territories (Rouget et al., 2006; Grant et al., 2007). The assessment of connectivity in river networks generally poses specific methodological difficulties (Peterson and Ver Hoef, 2010), as does more generally the contribution of specific landscape features to the accommodation of biological processes (Simberloff et al., 1992). Attempts to measure this interplay between landscape configuration and species movement, that we call functional connectivity, are still quite uncommon (Wainwright et al., 2011). Structural connectivity is defined as the adjacency or proximity of patches within a landscape and is a measure of the degree to which patches are connected without regard to organism behaviour (Taylor et al., 1993). Alternatively, functional connectivity is conceptually defined as the degree to which a landscape impedes or facilitates movement of organisms among patches (Bélisle, 2005). Functional connectivity is mostly derived from species range or dispersal studies, at best with dynamic process-oriented population or distribution models (Marion et al., 2012; Schurr et al., 2012). Managing for structural connectivity is thought to increase functional connectivity, yet this implication is not so straightforward (Tischendorf and Fahrig, 2000). Ideally, functional and structural connectivity should be integrated when providing guidance for management. That is what we try to accomplish for dendritic river networks in this paper.

To demonstrate connectivity, biotic processes involving species movement have to be studied over extended spatial and temporal scales. To this purpose, we analyze the well-documented

* Corresponding author. Tel.: +33 472 20 89 41.
E-mail addresses: Kris.van-looy@irstea.fr (K. Van Looy), Jeremy.piffady@irstea.fr (J. Piffady), Thierry.tormos@onema.fr (T. Tormos), P.Landry@oncfs.fr (P. Landry), Yves.Souchon@irstea.fr (Y. Souchon).

0304-3800/$ – see front matter
http://dx.doi.org/10.1016/j.ecolmodel.2013.11.010

re-colonization of the French River Loire basin by the European otter. The European otter is an emblematic species for nature conservation in a broad societal context; therefore it is often advocated as a model species in studies for ecosystem services and ecological networks (Bifolchi and Lodé, 2005). Especially with respect to river corridor functioning the otter is proposed as guiding and focal species (Barbosa et al., 2003) and indicator for the riparian landscape and its anthropogenic stressors (Robitaille and Laurance, 2002). To what extent anthropogenic disturbance of the riparian zone influences the corridor functioning is a central question in the understanding of ecological networks and the definition of restoration goals for river networks.

To determine connectivity in the river network based on the otter expansion, we use a graph theoretic method that integrates functional connectivity – derived from a colonization probability modelling – into a structural connectivity analysis. In this way we will highlight the separate functional and structural aspects of connectivity and ultimately create an integrated measure to both functional and structural connectivity in the river network. The overall objective of this integrated connectivity analysis is to identify priority conservation areas and effective corridors in the river network.

2. Methods

To determine key factors in the corridor functioning of riparian zones environmental gradients and dispersal processes at different scales need to be addressed (Rouget et al., 2006). In this context, connectivity is essentially used to address aspects of movement through the landscape, for which the measurement can be at the landscape-level, but for the process-based approach we also need to look to the more local context of habitat patches (Moilanen and Hanski, 2001). The European otter, as semi-aquatic mammal with high dispersal capacity, offers the opportunity to integrate these different scales. Where population expansion of the otter plays out at the basin scale, individuals experience the local habitat and its connectivity at the river segment scale. The otter is a highly mobile animal with home ranges of 2–100 km (Ruiz-Olmo et al., 2001). It is an opportunistic feeder, with a preference for fish but a broad range of other possible prey (crayfish, amphibians, insects, small birds and mammals) (Kruuk et al., 1997). A recovery of otter has been observed in the last decades for most of its Western European distribution, recorded for Central Spain (Cortés et al., 1998), Southern Spain (Clavero et al., 2010), Italy (Loy et al., 2009) and France (Lemarchand et al., 2007) after many decades of decline (Lodé, 1993). The Loire river basin represents one of the few West-European areas where a core of historical population persisted. A volunteer network gathered 5 surveys of otter distribution in the Loire River Basin over the last 25 years. Otter presence is ascertained by spraint marks. As otter spraints cannot provide information on otter abundance, only about presence, and furthermore the frequency of spraints may be very low when otters are at low densities (Macdonald et al., 1978), we are limited to a species distribution modelling capable of dealing with incomplete data. The consistent observation effort nevertheless allows for a reconstruction in well-defined time-steps for the natural re-colonization. The ascertained presence observations are attributed to the river segment in question, which is from then considered as colonized/occupied. For the survey periods the number of occupied segments raise gradually (1975–1985: 420 segments, 1985–1992: 585, 1992–1998: 923, 1998–2005: 1118, 2005–2011: 1790).

This information can be synthesized in a spread rate of 180 km annually over the river basin, from 1600 km in 1985 to 6300 km in 2011 of occupied river length in the surveyed network. Translated to the river segments at the colonization front this reveals a propagation speed of 10 km year^{-1}. Although the re-colonization is surely not fully accomplished for the Loire basin – only 37% of the surveyed network is occupied – the different parts of the catchment are reached by now (Fig. 1). As dispersing individuals will preferably choose the best available sites as a residence, this analysis of non-fully accomplished re-colonization of the river network allows discriminating the vital features in the riparian zone for dispersal and habitat selection (Ruiz-Olmo et al., 2001; Clavero et al., 2010).

In accordance to guidelines for otter survey and to avoid overestimating accidental visits of individuals to small water courses (Kruuk, 2006), only main streams in valley systems and rivers starting from a minimum catchment of >10 km^2 are entered in the surveys. The surveyed river network consists of 17,000 km river length, divided into 4930 river segments homogeneous in hydromorphological characteristics. A systematic sectioning into river segments and assembling of environmental and hydromorphological data for the riparian corridor in different buffer sizes (valley floor, floodplain, 100 m, 30 m, 10 m) is realized for the entire French river network with the hydromorphology audit system SYRAH (Chandesris et al., 2008). For the river segments information is collated from two spatial scales; the catchment's land cover information is gathered at regional sub-catchments (i.e. hydrological units delimited by water divides and river confluences) and local information on the riparian corridor is gathered for the individual river segments (Table 1). Temporal change of land cover is not considered in the analysis, as not all data sources could provide sufficient temporal coverage. Experiences with the data sources of catchment-scale land cover furthermore have evidenced it is rather stable for this period over the French territory (see http://www.eea.europa.eu/data-and-maps/data/corine-land-cover).

2.1. Graph theory application to connectivity analysis

Graphs are abstractions of landscapes, where patches are represented by nodes connected by links. Links stand for functional inter-patch connections, and in the landscape-ecological context they usually represent the dispersal potential or the number of dispersing individuals between patches (Urban et al., 2009). Integration of graph methods to structural connectivity measures are well-explored recently, and reviewed by Laita et al. (2011). From this review, the flux methods appear most promising to integrate functional connectivity. For the specific graph structure of dendritic river networks, the integral index of connectivity (Pascual-Hortal and Saura, 2006) offers the best perspectives as it implies a binary connection model.

Here, at first the graph's topological structure for the dendritic network structure of river systems is developed to model the riverscape at the segment scale (Erös et al., 2012). River segments are regarded as the nodes in the graph, whereas the confluences and segment junctions were considered as links in the network. Python scripts are developed to derive an adjacency matrix that depicts both network structure and numbers of connecting segments between all the nodes in the network. This structure enables collating observational and environmental data from different scales to linear entities, and afterwards interpreting the connections both in upstream and downstream direction. To this purpose an undirected graph model of the riverscape is built (Erös et al., 2011). We apply this graph structure first in the dynamic modelling of the species colonization to define functional connectivity over the network. The model results are then used in the integrated connectivity modelling by means of a weighted graph. Each node of the graph is weighted by the modelled colonization probability as a measure of functional connectivity.