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Connectivity loss in human dominated landscape: operational tools for the identification of suitable habitat patches and corridors on amphibian's population

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Abstract

Landscape connectivity is a key issue for biodiversity conservation. Many species have to refrain to move between scattered resources patches. This is particularly the case for the common frog, a widespread amphibian migrating between forest and aquatic habitats for breeding. Face to the growing need for maintaining connectivity between amphibians' habitat patches, the aim of this study is to provide a method based on habitat suitability modelling and graph theory to explore and analyze ecological networks. We first used the maximum entropy modelling with environmental variables based on forest patches distribution to predict habitat patches distribution. Then, with considerations about landscape permeability, we applied graph theory in order to highlight the main habitat patches influencing habitat availability and connectivity by the use of the software's Conefor Sensinode 2.2 and Guidos. The use of the JRC Forest/Non Forest European map for the characterisation of common frog terrestrial habitat distribution combined with the maximum entropy modelling gives promising results for the identification of habitat discontinuities within a regional perspective. This approach should provide an operational tool for the identification of the effects of "landscape barriers and corridors" on populations structure. Then, the method appears as a promising tool for landscape planning.

Key words: common frog, landscape connectivity, habitat suitability modelling, graph theory, maximum entropy modelling

1. Introduction

Landscape connectivity is considered a key issue for biodiversity conservation and for the maintenance of natural ecosystems stability and integrity. Landscape connectivity defines the degree to which the landscape facilitates or impedes movement among resource patches (Taylor and al. 1993). In fragmented and heterogeneous human dominated landscapes, movements across the landscape matrix area are key process for the survival of plant and animals species. Maintaining or restoring landscape connectivity has become a major concern in conservation biology and land planning (Pascual-Hortal and Saura 2008) and especially for amphibians. Indeed, amphibian's life cycle involves seasonal migrations between terrestrial and aquatic

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habitats which constrain them to regularly cross an inhospitable fragmented landscape matrix making them vulnerable to land degradation and connectivity loss (Allentoft and O’Brien 2010). Anthropogenic barriers as railways and major roads limit amphibians’migrations and movements. Many species have to refrain to move between small, scattered patches of different resources, instead of one, large patch. In this sense, habitat fragmentation constitutes the main driver of gene flow reduction (Allentoft and O’Brien 2010). This is particularly the case for the common frog *Rana temporaria*, a widespread amphibian in Europe occurring in various habitat types and migrating between forest and aquatic habitats for breeding (Miaud and al. 1999). The study focus on habitat availability and landscape connectivity, under the assumption that connectivity is species specific and should be measured from a functional perspective (Saura and Torné 2009). The focus is on viable habitat patches, in relation to the ongoing need for a holistic approach to landscapes and habitats. The overall goal is to find a continuum for habitat suitability of the species in question. Graph theory and network analysis have become established as promising ways to efficiently explore and analyze landscape or habitat connectivity. However, little attention has been paid to making these graph-theoretic approaches operational within landscape ecological assessments, planning, and design. We are working towards a methodological approach to address habitat quality assessment and connectivity from an operational point of view in order to support planning. To illustrate the basic principles of the proposed method, an ecological example using the European common frog *Rana temporaria*, in the French Alps region is presented. The approach is based on three main steps: i) Achievement of a probability of occurrence distribution map by the use of presence data and maximum entropy modelling ii) Simulation of dispersal areas in order to define the main connections between common frog ponds iii) Assessment of the main connected ponds by the use of graph theory and the software Conefor Sensinode 2.2 (Saura and Torné, 2009). We present here preliminary results on undergoing research, in order to exchange ideas in relation with this approach.

2. Methodology

2.1 Study site and sampling

This study focuses on the French departments Isère and Savoie (French Alps). This area is about 1415126 km^2 (see figure 1). The common frog is a typical species within this region where it breeds in various types of aquatic habitats. Because at the subalpine belt landscape connectivity is not the main driver of the frog dispersal patterns due to environmental constraints (*i.e.* climatic variables), we focused on the common frog populations occurring under the tree line (1400-1600 meters). The common frog was detected in 97 ponds under the tree line within this area. The sample design followed a genetic sampling strategy framework based on tadpoles between 1999 and 2002 (Pidancier and al. 2002). The geographic location of each sampling is known. For this preliminary study, we reduced the area to a surface of 4067 km^2 including 47 located ponds (see figure 1).

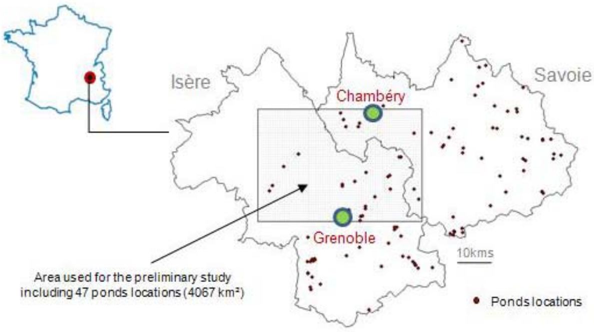

Figure 1: The study area.

2.2 Probability of occurrence distribution

We considered the 47 genetic sampling locations as presence data. It must be noted that the approach is based in present information only of the common frog within the study area. We used the maximum entropy modelling approach. In order to assess the distribution of the probability of detection of the common frog, we used in particular the software MaxEnt (Philips and Dudik 2008). Different environmental variables were analyzed and used to develop the probability of occurrence distribution map with MaxEnt. The common frog during its terrestrial cycle is very sensitive to the type of land cover to cross in order to reach its required forest habitat for summer and winter (Miaud and al. 1999). Based on radiotracking surveys and expert knowledge, the common frog seems to be very sensitive to the distribution of small forest patches around the pond area. Consequently, we computed and integrated in the analysis different environmental variables in relation to ecological and spatial requirements of the common frog. The forest habitat distribution around the aquatic habitat was also considered within the modelling:

1. Land cover based on Corine Land Cover 2006 (level 3).
2. Slope and elevation derived from a 50m DEM (French National Geographic Institute).
3. Landscape indices based on forest patches distribution from the European Forest/Non Forest map (resolution: 25m) provided by the Join Research Centre JRC. For this, we used Fragstats (McGarigal and Marks 1995) with a moving window of 3000m and we selected the following basics landscape indices: Mean Forest Patch Area, Largest Forest Patch Index and Forest Patch Density.
4. Distance to forest patches crossed by a river derived from a combination of the hydrological network map (French National Geographic Institute) with the European Forest/Non Forest map.

2.3 Connections between ponds

We quantified the connection between the ponds in relation with landscape matrix permeability by the use of a friction map and the least cost modelling. Least cost modelling allows to simulate the dispersal of the common frog in relation to the landscape matrix permeability between habitat patches. The matrix permeability is considered with the use of a friction map that provides inputs in terms of the ability of the common frog to cross the landscape matrix. The friction map layer is a raster map where each cell (landscape unit) expresses the relative difficulty of moving through that cell (Fulgione and al. 2009). In this study, the present friction map was computed by inversing the previous probability of occurrence distribution map from MaxEnt (Fulgione and al. 2009). Indeed, a fundamental assumption is that habitat suitability and permeability are synonyms, and that both are the inverse of ecological cost of travel (Beier and al. 2007). We added the highways and the urbanized areas to this friction map in order to integrate the main “impermeable barriers” for the common frog (i.e. high friction value). For the calculation of the least cost paths between each pond, we used the ArcView extension Path Matrix (Ray 2005).

2.4 Assessment of ponds’ importance for connectivity

We considered all the located ponds as nodes in order to use graph theory, in particular Conefor Sensinode software (Saura and Torné 2009). The least cost paths distances between the ponds allowed to calculate a set of quantitative connectivity rules between ponds. The software calculates a Number of Components NC index which identify a set of connected nodes (*i.e.* components) in which a path exists between every pair of nodes. The software also allows to calculate a Probability of Connectivity index (PC), which combines the attribute of the nodes with the maximum product probability of all the possible paths between every pair of nodes

(Saura and Torné 2009). All the more, the software provides to assess node importance for connectivity by removing systemically each node and recalculating the PC when that node is not present in the landscape. Node importance is quantified by an index dPC which corresponds to the importance of an existing node for maintaining landscape connectivity according to the PC index variation when the node is removed (Pascual-Hortal and Saura 2008). In our case study, we used a threshold dispersal distance of 1500m based on radiotracking surveys of common frog migration pattern between ponds and suitable terrestrials' habitats.

3. Results

3.1 Probability of occurrence distribution map and habitat suitability map

The use of 15% of the dataset for cross validation gives an Area under the Curve (AUC) of 0.75 for the ROC curve analysis which corresponds to a good discriminative capability between predicted presence and absence according to Pearce and Ferrier (2000). The figure 2 shows the resulting common frog probability of occurrence distribution map. The environmental variables with highest gain when used in isolation are Elevation and Largest Forest Patch Index in the jackknife test of variable importance in MaxEnt. MaxEnt also calculates several threshold values at each run and values exceeding them may be interpreted as reasonable approximation of the potential distribution of the considered species suitable habitat. As suggested by Phillips and Dudik (2008), we used the 10 percentile training presence (mean = 0.339) in order to obtain the potential distribution of the common frog in relation to suitable terrestrial habitat distribution (see figure 2). The potential distribution of the common frog obtained (see figure 2) allows to identify the effect of the dense urbanized areas and highways as main barriers and unsuitable habitats. This distribution also suggests the potential presence of discontinued potential suitable areas for the frog depending on forest patches distribution impacted by human activities. In this context, further genetic considerations will help to quantify and identify the disconnections between frog populations in relation to human dominated areas distribution.

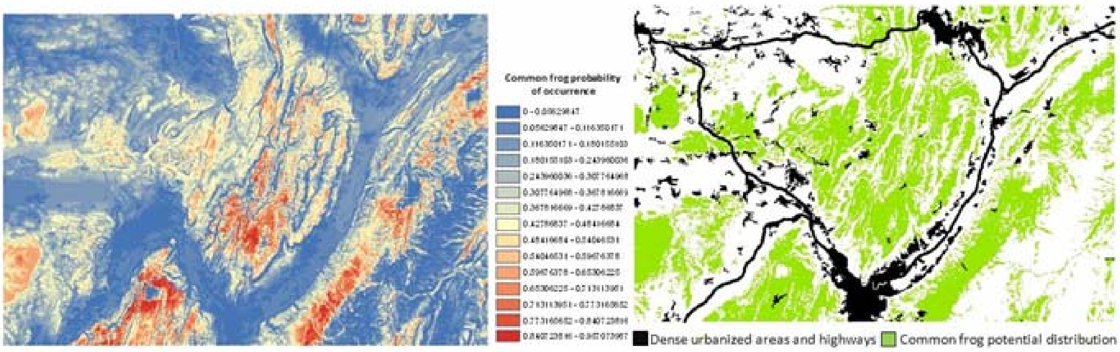

Figure 2: Probability of occurrence distribution for the common frog with the maximum entropy modelling and resulting potential distribution of the common frog (10 percentile training presence of 0.339 as the probability threshold) (area of 4067 km²).

3.2 Ponds' importance for connectivity

The use of the NC index (see figure 3) provides a rapid identification of the connected ponds in relation with landscape matrix. In our case study, most of the ponds are isolated by distance and few ponds can be considered as connected in term of seasonal migration patterns. All the more, most of the connected ponds identified are located in homogenous suitable habitat. This is due to the orientation of the ponds location dataset for genetic analysis (genetic isolation by distance). Within this context, we plan to improve the analysis using a more detailed pond' distribution dataset in order to assess local connectivity in the near future. On figure 3, some ponds isolated and closed to urbanized areas appear as important for regional connectivity (high dPC value). This may suggest that these ponds could be considered as critical isolated ponds in relation with barriers in a human dominated landscape context (presence of disconnections between suitable large areas for the common frog). For the moment, this interpretation of the dPC has to be considered with caution given that we did not use yet all the exisiting ponds locations within the area (missing nodes). We plan to complete the study with the computation of a dPC index based on genetic distance between ponds for the quantification of the potential genetic connections.

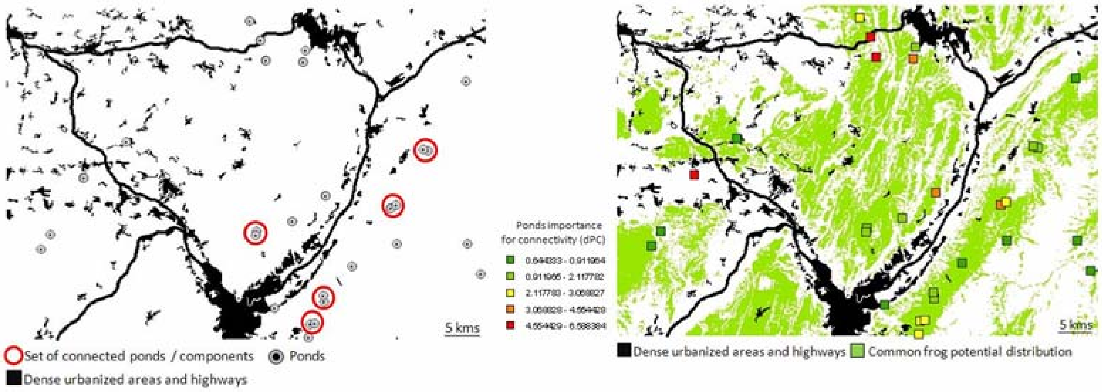

Figure 3: Set of connected ponds (components) identified with the computation of the Number of Components index (NC) and ponds importance for connectivity based on the computation of the dPC index (warmer colours correspond to a highest importance for connectivity).

4. Discussion

In this preliminary study, the use of the JRC Forest/Non Forest European map for the characterisation of common frog terrestrial habitat distribution combined with the maximum entropy modelling gives promising results for the identification of discontinuities in distribution within a regional perspective. This approach in tandem with genetic considerations should provide a tool for the identification of the effects of "landscape barriers and corridors" on populations structure in relation to common frog and its terrestrial habitat requirements. The use of a friction map combined with least path modelling appears also as a crucial key issue for the quantification of connections between habitat patches when dealing with landscape matrix permeability. Even if an efficient calibration of a friction map is possible for a local approach (Janin and al. 2009), the computation of a relevant regional friction map remains quite difficult for the common frog given the existence of heterogeneity in dispersal patterns driven by local environmental conditions. This suggests that it should be more efficient to consider regional connectivity for amphibians from the point of view of genetic and spreading diseases as the chytrid fungus (Rödder and al 2009). Landscape connectivity should be better considered for a local perspective in relation with common frog migration patterns between its aquatic and terrestrial habitats. In this context, the use of a graph theoretical approach appears as a promising tool for the assessment of local landscape connectivity for the common frog given that the Conefor Sensinode software provides a powerful tool integrating considerations about habitat patches distribution and suitability in a landscape matrix context surrounding habitat patches. Moreover is proven as an operational tool to identify barriers and important patches for planning purposes.

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