Connectivity and landscape patterns in human dominated landscape: a case study with the common frog Rana temporaria

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Abstract

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. A wide range of methodological approaches can be involved in such studies. Spatial distribution analyses are common tools but can hardly integrate connectivity. We do here suggestions to apply graph theory and least cost path approaches in a specific application related to common frog habitats connectivity.

Amphibian's life cycle involve seasonal migrations between terrestrial and aquatic habitats which constrain them to regularly cross an inhospitable fragmented landscape matrix. Thus, there is a growing need for maintaining and restoring landscape connectivity between their habitat patches. This is especially 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.

The aim of preliminary study is to explore a method based on habitat suitability modeling and graph theory in order to analyze an ecological network. In order to assess in which manner habitat patches distribution can affect landscape connectivity between ponds, we use both configuration and distributions of suitable forest patches as model inputs.

The link between common frog occurrence and forest patches configuration and distribution is defined with a probabilistic model from sampled data and relevant indices. Especially, elevation, land use distribution, distances to forest patches, distance to rivers, and landscape indices computed from forest patches distribution were shown being the main significant environmental variables influencing habitat patches distribution. In our application, we obtained then a suitable habitat patches distribution map by the use of ponds occupancy location data and maximum entropy modelling. Then, we applied least cost path modelling and graph theory approach in order to highlight the connected ponds and their importance for regional connectivity.

These results emphasize the potential of maximum entropy modelling, and graph theory approach for integrating connectivity in landscape planning. The quantification of landscape matrix permeability in relation with the common frog dispersion patterns appears as limited in order to quantify edge between nodes for the design of a graph integrating ponds as nodes for a regional perspective. Nevertheless, this method combined with the use of genetic markers may be useful to assess main barriers and corridors for the common frog from a regional to a local perspective for planning. In this context, the use of genetic distances could be considered as a good surrogate to the use of least cost path as edges in a graph theoretical approach for studying connectivity.

Keywords: graph theory approach, maximum entropy modelling, fragmentation, connectivity, barriers and corridors, environmental planning, habitat suitability modelling, common frog.

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 (Wiens and al., 1993). 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 habitats which constrain them to regularly cross an inhospitable fragmented landscape matrix making them vulnerable to land degradation and connectivity loss (Joly and al., 2001 ; Pope and al., 2000 ; Hamer and McDonnell, 2008 ; Allentoft and O'Brien, 2010). Anthropogenic barriers as railways and major roads limit amphibians' migrations and movements (Fahrig and al., 1995). 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 (Hitchings and Beebee, 1997 ; 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 (Gasc and al., 1997 ; Miaud and al., 1999 ; Palo and al., 2004). The study focus on habitat availability and landscape connectivity (Urban and Keitt, 2001 ; Pascual-Hortal and Saura, 2006), under the assumption that connectivity is species specific and should be measured from a functional perspective (Saura and Torné, 2009). 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. In this study, we decided to use the software Conefor Sensinode 2.2 (Saura and Torné, 2009), a proven efficient tool for landscape connectivity assessment by the use of graph theory (Pascual-Hortal and Saura, 2008).

To illustrate the basic principles of the proposed method, an ecological example using the European common frog *Rana temporaria* in the French Alps region have been chosen. We present here some preliminary results in relation with the computation of the inputs needed for defining the underlying graph in order to study it's connectivity. The nodes of this graph are defined from estimations of the habitat distribution. Edges define possible paths of individual movements between habitats throughthe landscape matrix. On the application point of view, the graph gives a functional representation of common frog's habitats network.

The following methodological steps explored for building this graph are presented in this study: i) Achievement of a habitat suitability map (in this study we computed 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 Conefor Sensinode.

1.Study site and sampling

This study focuses on the French departments Isère and Savoie (French Alps). This area is about 1415126 km² (figure 1). The common frog is a typical species within this region (Castanet and Guyétant, 1989) 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 km² including 47 located ponds (figure 1).

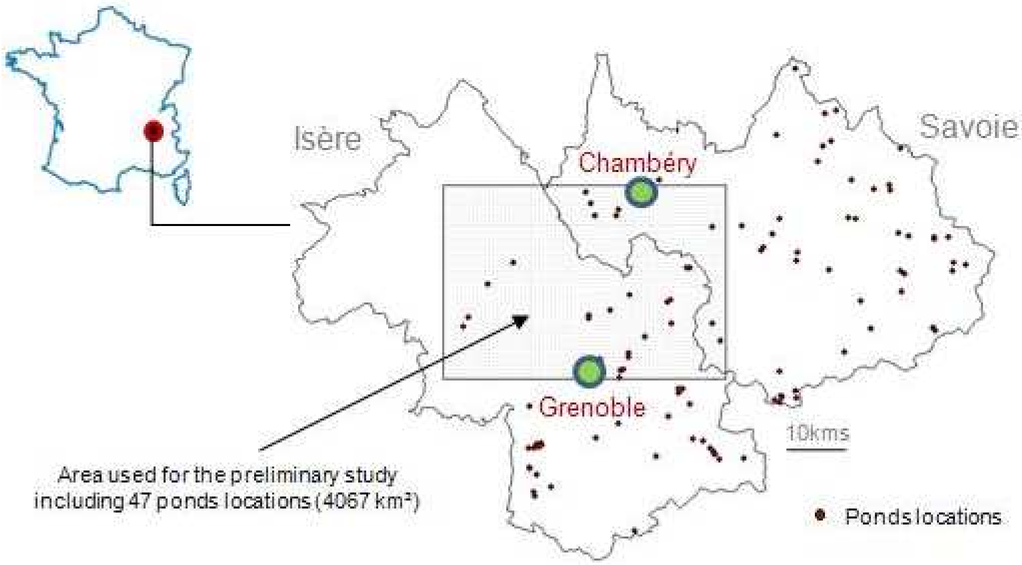

Figure 1. The study area (the altitude of the ponds located on the map ranges from 200m to 1500m which correspond to ponds occurring under the tree line).

2. Probability of occurrence distribution

We used the maximum entropy modelling approach (Phillips and al., 2006 This approach allows to predict the distribution of a target species' probability of occurrence in relation with environmental variables and only presence data. Software tool MaxEnt was used for this (Philips and Dudik, 2008).

We considered the 47 genetic sampling locations as presence data.
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 ; Pahkala and al., 2001 ; Palo and al., 2004). 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 (Pekkarinen and al. 2009). 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. The moving window of 3000m corresponds to the maximum frog's dispersal distance area observed during a radiotracking surveys.

4. Distance to forest patch crossed by a river derived from a combination of the hydrological network map (French National Geographic Institute) with the European Forest/Non Forest map.

The estimate of relative contributions of the environmental variables to the Maxent model is as follows: 26.7 % for the altitude, 22.2% for the slope, 21.1% for Largest Forest Patch Index, 11.6% for the distance to forest patch crossed by a river, 8.8% for Mean Forest Patch Area, 8.0% for Forest Patch Density and 1.6% for land cover. 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). We plan to make model iterations and to make a more strict variables selection by the use of the jackknife test provided by Maxent. We will also test model sensitivity to different amount of test data (AUC and omission rate). All the more, the moving window of 3000m corresponds to the maximum dispersal distance area observed by a radiotracking surveys and we plan to compute landscape indices with a moving window of 1500m corresponding to the mean dispersal distance observed for the common frog as suggested by expert knowledge and radiotracking surveys. In order to test and illustrate the next methodological steps of this approach, we present here a first model output (figure 2).

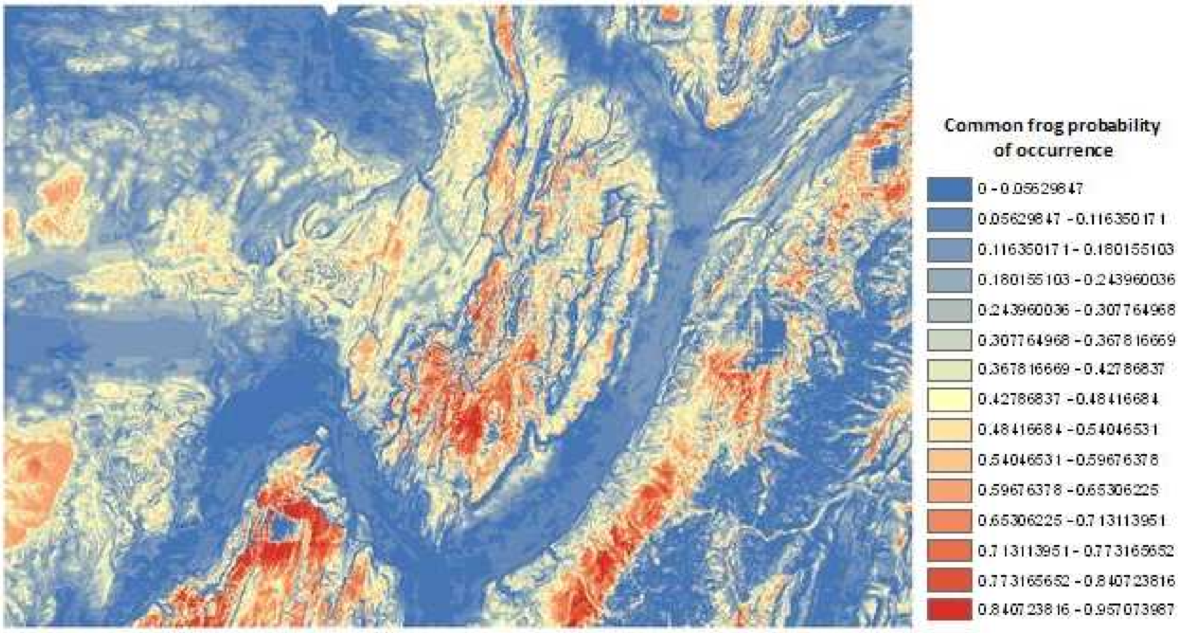

Figure 2. Probability of occurrence distribution for the common frog with the maximum entropy modelling (area of 4067 km²). Warmer colors show areas with better predicted conditions (AUC of 0.75 for the ROC curve with 15% of the dataset for cross validation).

MaxEnt 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 (figure 3).

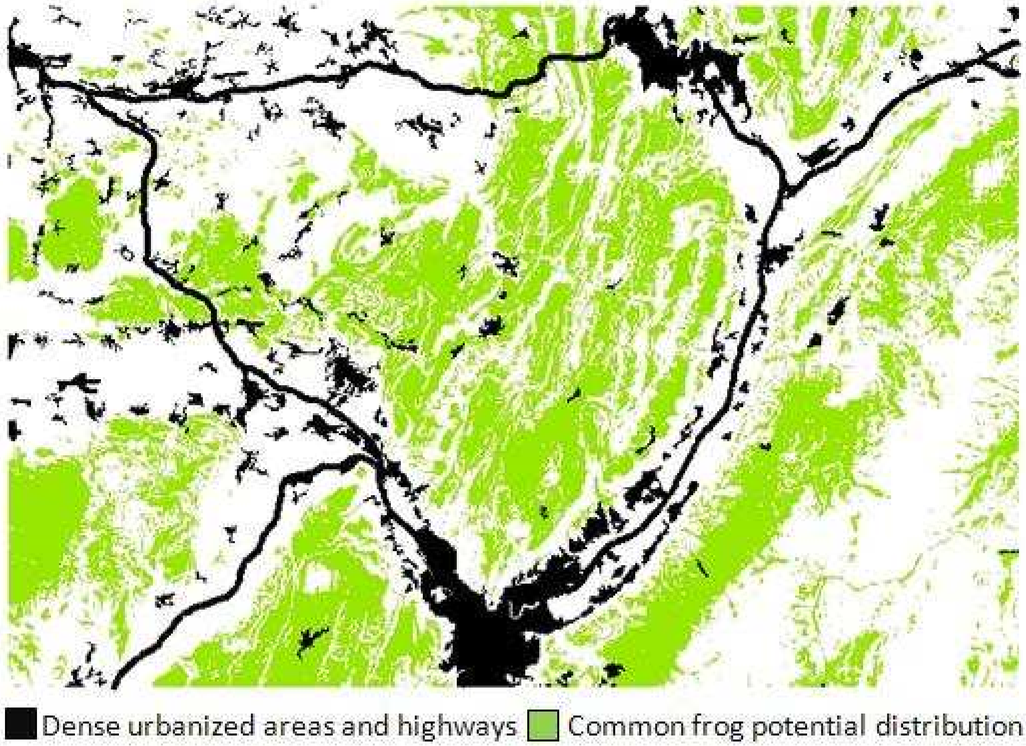

Figure 3. Potential distribution of the common frog (10 percentile training presence of 0.339 as the probability threshold) (area of 4067 km²).

The potential distribution of the common frog obtained (figure 3) 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.

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 (Ray and al. 2002) allows to simulate the dispersal of the common frog in relation to the landscape matrix permeability between habitat patches. The approach is based on the calculation of the amount of energy that an individual looses in its movement during a walk from a habitat patch to another one. In this case study, we considered frogs as individuals and the movement as a "walk" from a pond to another one.

The matrix permeability is considered with the use of a friction map that provides inputs in terms of the ability of the individuals 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. The tool MaxEnt (Fulgione and al., 2009) was used for this purpose. 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). These conditions can be considered as accepted in our application. Moreover, we added specific spatial constraints in this friction map. More precisely, in our case, the main “impermeable barriers” for the common frog (i.e. high friction value) are the highways and the urbanized areas.

For the calculation of the least cost paths between each pond, we used the ArcView extension Path Matrix (Ray, 2005). This methodological step will be followed by a comparative approach with the computation of friction values based on expert knowledge and radiotracking surveys.

4. Assessment of ponds’ importance for connectivity

We build then a graph whose nodes stand for the located ponds. Edges between nodes are valuated as the least cost paths distances between the ponds.

In practice, we use Conefor Sensinode (Saura and Torné, 2009). 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 (figure 4). The tool estimates a Probability of Connectivity index (PC), combining the node attributes with the maximum product probability of all the possible paths between every pair of nodes (Saura and Torné, 2009) (PC equals 0 when nodes are not connected). All the more, the software helps to assess node importance for connectivity by removing systemically each node and recalculating the PC when that node is not present in the data set. 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) (figure 5).

In our case study, the possible paths between every pair of nodes correspond to the least cost paths computed in the previous step. And we used a threshold dispersal distance of 1500m based on radiotracking surveys of common frog migration pattern between ponds and suitable terrestrials’ habitats. In this context, when a least cost path distance between two nodes (ponds) is higher than 1500m the nodes are considered as no connected and the PC equals 0.

The use of the NC index (figure 4) 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 ponds’ distribution dataset in order to assess local connectivity in the near future.

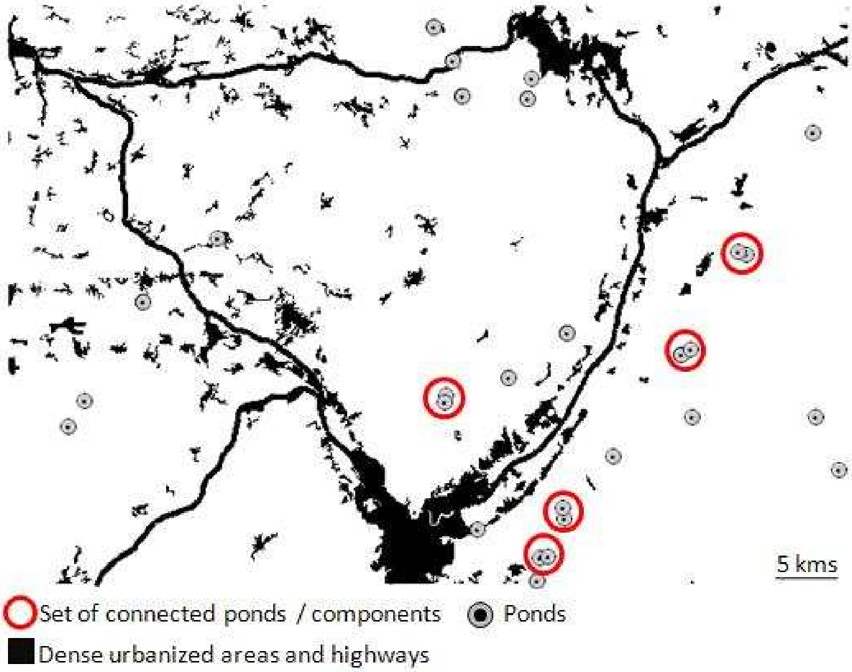

Figure 4. Set of connected ponds (components) identified with the computation of the Number of Components index (NC) using Conefor Sensinode software with a dispersal distance of 1500m (Nodes are not connected when PC equals 0 which correspond to a least cost path distance between nodes higher than 1500m).

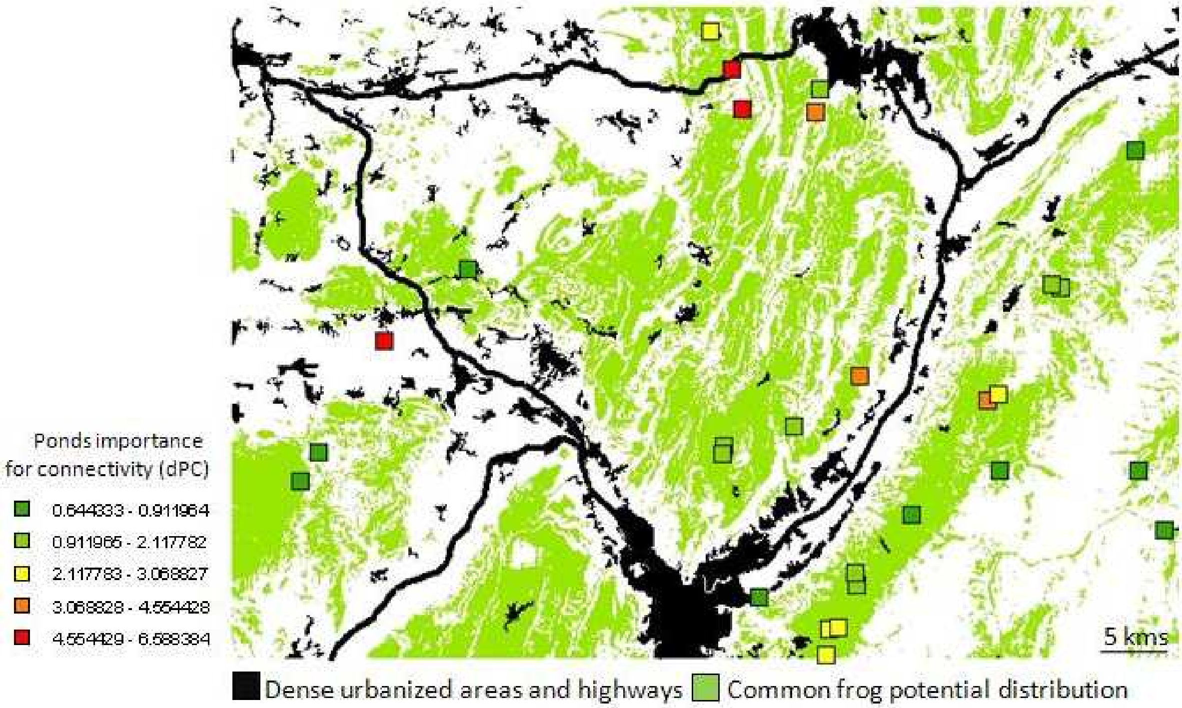

Figure 5. Ponds importance for connectivity based on the computation of the dPC index using Conefor Sensinode software. Warmer colours correspond to a highest importance for connectivity.

As shown in figure 5, 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 existing 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.

5. 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.

Conclusion

In this connectivity habitat modelling approach, the main interest of the graph theoretical approach is its flexibility in the consideration of quantified links between nodes in relation with the study assumptions and knowledge about the target species. Indeed, links between nodes can be quantitative links as possible paths between nodes (least cost paths for example) or probabilities of connection (based on genetic distance or dispersal test for example) or

The use of a habitat suitability map via a modelling or an expert knowledge approach is essential when considerations about habitat patch availability and sustainability are needed in a landscape connectivity study applied to an animal species in order to assess which patches are critical for connectivity.
In this context, quantification of links between nodes (habitat patches) in relation with animal species abilities to cross landscape matrix appears also as a critical step because of its need of ecological realism. In many case, the quantification of landscape permeability remains difficult and consequently is often based on assumptions and simplifications. This appears in our study case with the common frog for which the quantification of landscape matrix permeability and paths between ponds for a regional perspective needs more discussions and improvements. Even if these limitations exist, this preliminary study appears as helpful for the consolidation of our methodological framework. And the use of a genetic approach based on genetic distance between common frog populations should be a relevant surrogate to the use of potential paths between ponds quantified with a landscape permeability approach.

Acknowledgements

This research was supported and funded by the Interreg Alpine Space Program Econnect (reference number: 116/1/3/A). We thank Santiago Saura for his advice on the subject and his help on using the software Conefor Sensinode.

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