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CHARACTERIZING GEOGRAPHICAL SPACE TO ANALYZE FAUNA MOVEMENT

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1 – CONTEXT

Environmental preoccupation has been increased with urbanization and in parallel with climate changes concerns. Ecology and especially biodiversity are thus more and more integrated in regional development (Veyret & Simon, 2006). Plans are elaborated on field observations and on scientific methodologies. They require data collection concerning biodiversity: plants and animals censuses for identification and evolution, environment and landscape features and their impacts on wildlife. The term biodiversity verifies multiple aspects and levels of detail, from individuals to ecosystem organisations (Wilson & al., 1993) (Arnould & Simon, 2007).

The transverse definition of biodiversity implies consideration for the dynamics of whole areas and communities (Duffy, 2002). Some conservation proposals are oriented on the protection and the creation of corridors, natural ones based on the proximity of favourable areas, or built ones like wildlife crossings (Bonnin, 2008) (Bennett, 1998). The approach aims at rehabilitating landscape continuities to encourage species moves (Forman & Godron, 1986) (Burel & Baudry, 1999). Indeed, spatial fragmentation comes mostly from human infrastructures and activities. This parameter is linked to loss of viable habitats for species and decrease of gene flows (Van Der Ree & al., 2009). Studies on animals' movements allow then to evaluate the effect of modifications in spatial environment.

2 – OBJECTIVE AND APPROACH

The work deals with the analysis of relations between spatial features – topography and landscape – and species movements. The goal is to determine relevant data and data modelling for describing the space so that to represent and analyze fauna movements. Depending on the spatial constraints and the animals' special needs, the geographic space may be read through different points of view and some specific aspects may be more or less relevant depending on the area. We use spatial data analyses that are dedicated for studying landscape characteristics and for extracting obstacles and potential continuities for movements. The heterogeneity in geographical area type and in animal movement nature brings the issue of adaptation in data specifications and in data analyses.

To tackle the determination of adapted spatial data and functions for fauna movement analyses, we specify a spatiotemporal model containing the relevant elements in the study. The model enables to list concepts and useful data as well as to relate them. Such formalization helps highlighting the land settlements and the field characteristics that interfere with animals' movements. Different specifications of the geographical data are integrated and possibly compared. Data enrichment may concern precise 3D component for topographic elements and for land shape, added semantic information or topological relations.

The approach lies on proposing a modelling of movements by integrating the animal behaviour and the spatial constraints for each species. Many researches in ecology study relations between animals' reactions or social organizations and their environment (Wynne-Edwards, 1962) (Lachat Feller, 1993). We especially focus on modeling how the spatial features act upon the movements. Spatiotemporal modelling is used to monitor and analyze complex ecological dynamics like vegetation changes (Kulik & al., 2011). In our case, modelling implies to characterize the space so as to highlight the impacts of regional development dedicated for fauna movements. The characterization deals with identifying obstacles and corridors. It includes the mapping of the species' functional space. We call functional space the spatial organization that corresponds to the needs and uses of a species (COMOP, 2009). Species, not to say animals, do not interact with the space they live in the same way. They have specific land use because of their short or longer term needs and that leads to different apprehension of their environment.

The functional space can be organized in locations bound to activities such as feeding, resting, breeding or migrating. The potential attractive areas are to be located: resources, rest areas, conflict areas such as roads. Though, those meaningful elements are different from one species or even one animal to another, especially in adaptable species. The interesting part is so to obtain a multiple reading of the space. Several meanings are potentially associated with the same topographic element depending on the species, the type of movements, the biological and spatial constraints, and this offers a flexible reading of the space. In our work, interactions between animals are not taken into account except through particular conflict area.

To define spatial characterizations and to organise it in a spatiotemporal model, we define a methodology in two steps.

The first part of the methodology consists in analyzing information that concerns the space and the movements. It is described in paragraph 3. For the space description, the analysis can be run for calculating indicators based on the landscape features: for example, network connections, proximity and heterogeneity of the wooded areas. For the data collected on the animals, it may be locations via telemetry emitter-receiver systems or via GPS collars. These tracks offer the opportunity to visualise the behaviour of particular animals and to search for correlations between the movements and the field shape and elements. Depending on the accuracy of the data, this can help to precise movement patterns for the species.

In the second step of the methodology developed in paragraph 4, we work with trajectories built from hypotheses on an animal behaviour and on its reaction facing spatial elements. This implies simulation functionalities that accept as parameters a formal animal moving on a characterized space. The environment is characterized by topographic constraints and also by landscape features. The behaviour and the objective of the animals are parameterized and the values of these parameters can be modified and tested through the resulted trajectories. Simulating trajectories on a described environment offers indications for spatial planning. For instance, the creation of a corridor like an animal tunnel or of an obstacle like a road can be tested on coherent trajectories.

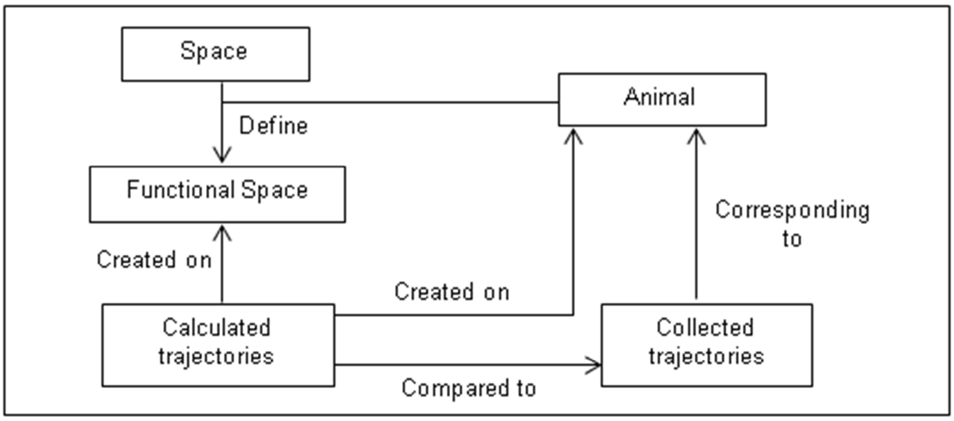

Fig. 1 Concepts organisation

3 - ANALYSIS AND REPRESENTATION OF MOVEMENTS AND FUNCTIONAL SPACE

The first part of the methodology consists in analyzing animals' moves from collected locations by radio tracking or GPS. The goal is to integrate the locations with the geographical data and to overlay them so as to interpolate trajectories and study potential relations between movements and topographic space.

This part deals with the analysis of the space to identify meaningful features influencing on movements. For that purpose, we have to determine which type of analysis would be interesting to lead. One type of analysis consists in studying the topographic space. A second analysis can be pursued on movements: calculation of locations and tracks indicators. Then relations between space features and animals' movements represent the main analysis so that to characterize space through themes. The data and the analysis methods are described in the next section.

3.1 - Space analysis

Analysis of spatial components already discloses different reading of the space and so one of the spaces of the movements. Locations, surfaces and relative positions of the spatial features determine the land use by an animal.

In our work, we use topographic data from geographical databases and land use information from image analysis. Topographic data is used from BD TOPO® produce by IGN, the French mapping agency. Data are structured in anthropogenic and natural themes: buildings, roads, hydrography network, and wooded areas. The relief is represented by a DTM. Landscape analysis provides useful values on the general properties of an area: diversity of land use, connectivity. Independently of species but by considering that the fragmentation of habitats hinder movements, Shannon-Wiener index gives indications on the type of area for species. Heterogeneity and connectivity measures complete the analysis (Burel & Baudry, 1999).

Space is also read through the topological relations of the topographic elements. The definition of a geographical area by segments and faces enables to emphasize the connections of the road or the hydrography networks, as well as the dispersion and density of buildings. It is for example possible to study the distribution of linear infrastructures like roads by separating the area into faces which sides are the infrastructures. For each faces, we calculate the following indicators: the geometric boundaries types – e.g. the road classification -, the number of buildings, the percentage of wooded surface, the presence of water resources.

Another topographic database is used to compare the contribution of a different information source. Data from Plan Rhône® were collected for a flood management project in the Rhône valley (IGN, 2008). Dedicated data meet the demand of flood prediction and response such as the hydrography theme enriched with geometric precision and additional content. Relevant objects for floods studies are indeed included like dykes, banks and slope breaks. It is noticed that animals exploit those types of element that facilitate crossings, and similar infrastructures are especially set in that purpose (Hertig & al., 2006). In that context, it is relevant to consider the enriched data into the space analyses and even more for the study of species functional spaces.

3.2 - Movement analysis

The second analysis concerns the data corresponding to animals' movements. This type of data is mostly obtained from GPS collars and by radio-tracking techniques.

Important specifications about data of fauna movements deal with the frequency and the spatial precision of the recorded positions. According to the frequency, the observed dynamics vary. If positions are known every hour or less, it is possible to describe quite precisely the trajectories and to assume interactions between animals and spatial elements. The described movement corresponds to daily behaviours, generally in an animal territory. Positions taken every day and up to every month allow visualising long-time migrations, or phenomena like juvenile dispersion. Apart from the frequency consideration, the data can give indications on the habitat and on the preferred areas such as cultures, forests, peri-urban. They also can show some natural or human barriers, at a population size. For example, the study by Marchandeau & al. (2003) show a division in a European Rabbit population (Oryctolagus cuniculus) due to water ponds. In figure 2, locations of one Red Fox (Vulpes vulpes) during 18 months give indications on its home range mainly near houses (Raton, 2004).

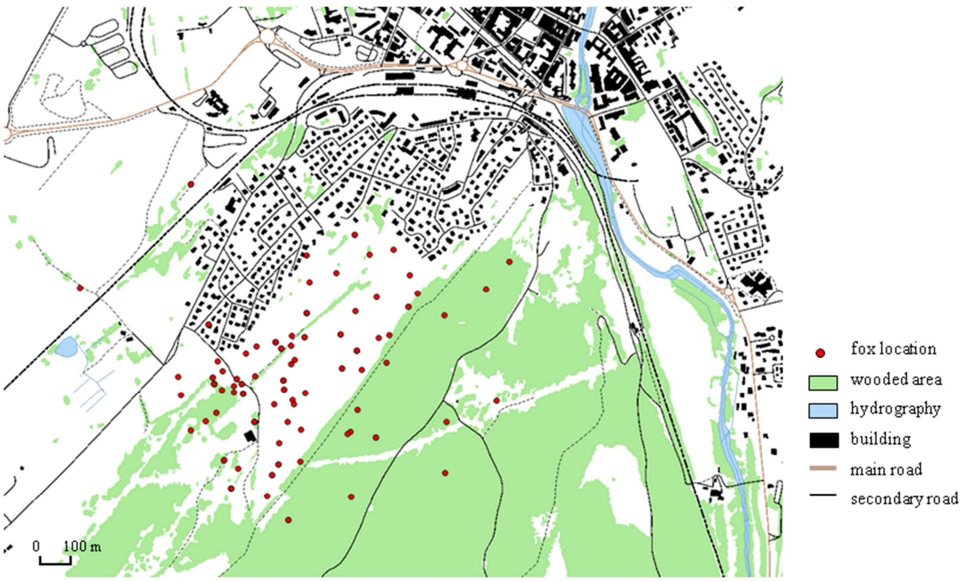

Fig. 2 Locations by radio-tracking of a Red Fox during 18 months between 2004 and 2006 (source: Entente Rage Zoonoses).

Location points being linked to time and date, it is interesting to divide the points into stops and effective moves (Calenge & al., 2009) (Buard & Brasebin, 2011). Depending on the time scale as well, stops and moves may be significant for the characterization of the global movements. The result is a sequence of moves that can be linked to activities like foraging, resting, or searching for new land at a season change

(Fryxell & al., 2008). The time of the day, the season, the biological rhythm of the species are also to be taken into account and overlaid with the spatial environment (Spaccapietra & al., 2008).

3.3 - Relations between space and species movements and definition of the functional space

For the study of trajectories, we are interested in correlations between movements of the species and the spatial distribution of topographic and landscape features. The influence of roads and buildings on Roe Deer movements (Capreolus capreolus) is highlighted by Coulon & al. (2008). Roe Deer are more likely to stay in areas far from roads and buildings. The impact of such human infrastructures is mainly due to the traffic and the implied human activities. Relations between field shape and cougars' moves (Puma concolor) are studied by Dickson and Beier (2007). This carnivore tends to favour soft slopes to move, which illustrates the impact of the relief on animals land routes. In a general way, animals like mammals move in their territory via known paths (Raton, 2004). They follow a movement's network in which they recognize tracks, smells or unusual disturbance.

We plan to identify relations between movements and space by identifying the topographic elements that influence animals' moves. Spatial analysis enables to highlight correlations between a trajectory and a characterized space. Each species perceive spatial elements differently according to their needs, their capacities and their body size. For instance, obstacles are not the same for roe deers than for wild boars. Wild boars tend to cross roads more often than roe deers even though roads represent barriers for the both species. Considering a third species, the Terrestrial Salamander (Plethodon cinereus) studied by Marsh & al. (2005), roads are also barriers and the impact is quantified to a diminution of half the movements of the species.

For each species we can define a functional space based on theory and observations. The figure 3 shows the extraction of potential avoided areas for two different species. In the case of the Red Foxes, we only consider road network as avoided, whereas for the European Pine Marten (Martes martes), we add houses and hydrography.

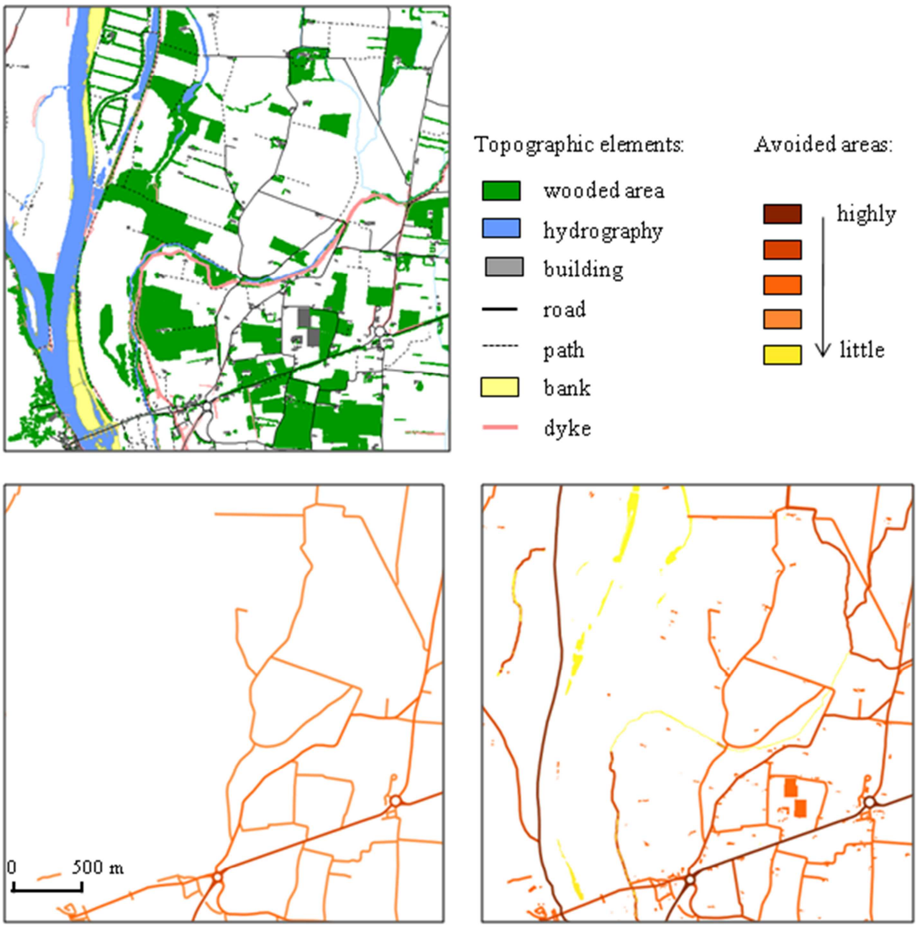

Fig. 3 On the same area, representation of the topographic features and mapping of theoretical avoided areas by Red Foxes and European Pine Martens

3.4 - Spatial analyses for characterizing movements and topographic relations

For the study of trajectories, we are interested in analyzing spatial correlations between movements and the topographic data. Undergone analyses include the results of movements and space characterizations run independently as described previously.

The spatial requests consist in proximity and intersection operations between tracks data and topographic objects. Collected location tracks are integrated in a map of topographic data. The topographic neighbourhood of each location is determined within a certain distance: roads, buildings, wooded areas, hydrography and slopes. The surroundings of the tracks give an idea of the movement pattern of an animal: is he generally near buildings, roads or water, and for how long?

Besides, movements can be interpolated thanks to the spatial features between two location points. Trajectories can be built by taking into account the environmental factors: slopes, barriers or corridors, continuities in the type of habitat.

In the same manner that time scale influences the characterization of sequences on movements (cf. paragraph 3.2). The level of detail impacts on the characterization of potential specific structures. Insufficient or inadequate level of detail of information leads to incomplete relations identification between infrastructures and movements. This last part deals with the aim to identify accurate data specifications for analysis of movements by testing different data.

Considering the complexity and the richness of relations between space and species movements, we propose to organise the key concepts and the analyses methods.

4 - SPATIOTEMPORAL MODEL

We describe the proposed spatiotemporal model that formalizes the space and the movements. The data model should represent those different elements and help to carry out analyses on relations between space features and fauna movements. It implies that adapted concepts on the topic must be included: topographic elements enriched with landscape indicators and a formalisation of the species movements. The model should enable the creation of trajectories according to the environment. It requires a time management.

4.1 - Data and functions model

The data model aims at representing and organising concepts linked to species of which we study the movement, and concepts corresponding to the space in which they live and move. The model should describe relations among geographical concepts as well as relations between the species behaviour and their movements.

The data model includes objects from different themes, and organises them. Indeed, the relations between objects are multiple. It can be a hierarchical and inheritance relation between two classes, like the class for highways that inherits the general properties from the class for road. It can also be a relation of association between two concepts: for example banks and dykes classes are both hydrography elements. Other relations of dependency are established: for instance calculation of landscape metrics, like a fragmentation measure, is partly based on the topographic description of the studied area.

We begin by defining the general themes as it is showed on figure 4: the topographic elements, the landscape, the species behaviour, the functional space and the movements. The main relations between the themes lie in the definition of the functional space which depends on the species and their apprehension of the environment.

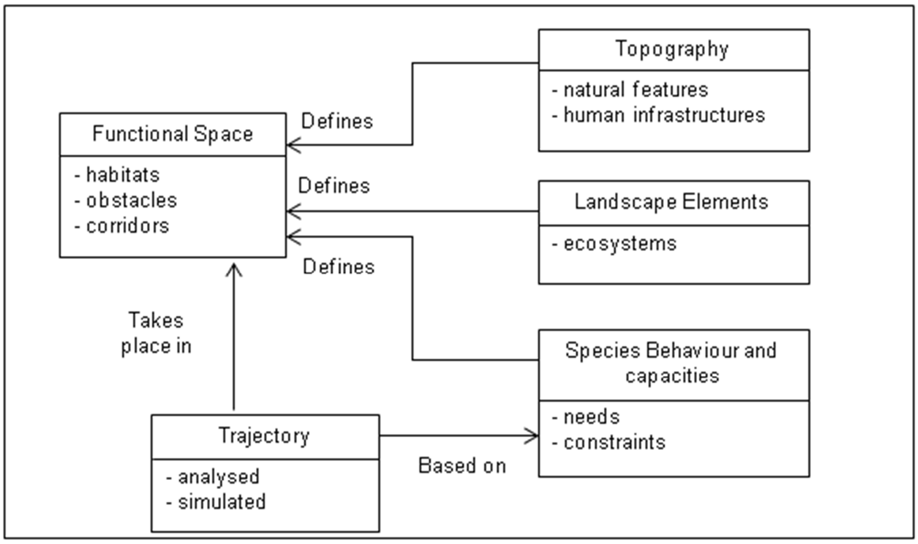

Fig. 4 Main classes of the data model and their relations

Species have various perceptions, uses and reactions when confronted to spatial elements. The general behaviour of red foxes (Vulpes vulpes) and of roe deer (Capreolus capreolus) is based on a different perception of their environment. Urban areas are often a part of the territory of red foxes where it is deserted by roe deers. Resources availabilities explain partly this distinction. Red foxes find food next houses, and they are to cross roads and get close to human infrastructures to reach it. Roe deers seek for resources in wooded or farming land and are less likely to go near houses.

The diverse use of the spatial elements by species is important for mapping accurately the functional space. Obstacles and preferential areas used by animals for moving influence their trajectories, as well as their needs at a certain time.

As it is suggested by the main classes of the model, each concepts and relations are compounded. The organisation of the elements in the model is complex inferring on the reality. Though, the model enables to simplify and represent accurately the elements fit to the topic.

We detail the model by other classes implied by the Functional Space class. Relations between the classes are hierarchical and associative. Topographic and Landscape Elements class through species behaviours defines the classes concerning the functional space. For instance, obstacles may correspond to a road (with linear geometry, road traffic intensity), to a building (with localized surface, pedestrians presence) or to a cultivated field (with open area, agricultural activities). Obstacles are then determined thanks to a function based on spatial elements like topography and landscape indicators, and a particular species.

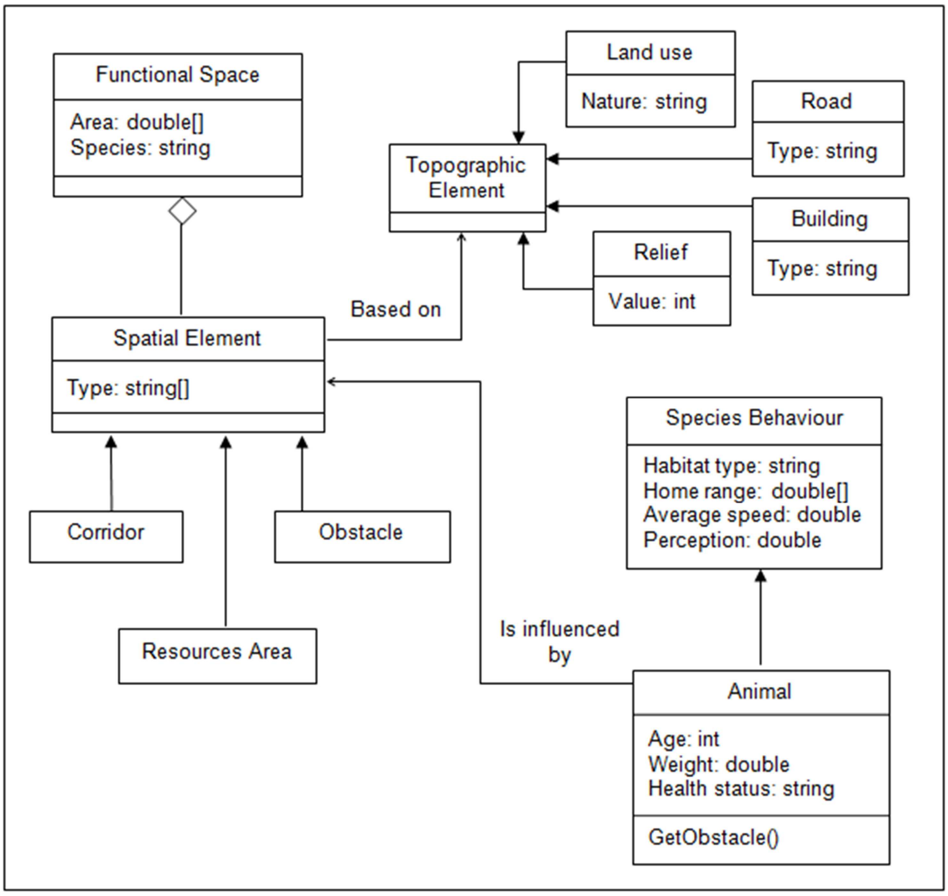

Fig. 5 Determination of obstacles inheriting from Spatial Element class in the data model

The figure 5 is an extraction of the proposed model. The selected classes intervene in the determination of obstacles for one animal. Even if geographic reality is simplified, its relevant aspects for studying fauna dynamics are enclosed.

4.2 Data Model implementation

The presented data model is a proposition to carry out spatial analyses and to determine what information is relevant for studying the influence of spatial features on fauna movements. We use simulated trajectories to test the model. The agent (Treuil & al., 2008) is used to calculate the displacement of animals on a topographic space. Collected trajectories from tracks are captured and compared. The calculation of trajectories may encounter adaptation in the treatments depending on the spatial and temporal level of detail, and the unknown behavioural features.

Agent modelling enables to confront hypotheses on the movement behaviour of the species, the apprehension of the space by an animal, and the data needed for the space description. An agent is in our case an animal with needs, objectives and constraints. Its daily objectives are diverse like foraging or resting; other objectives may be on a larger scale like finding a new territory. The environment such an agent evolves in is composed of the topographic elements that are characterized for the animal land use and movements.

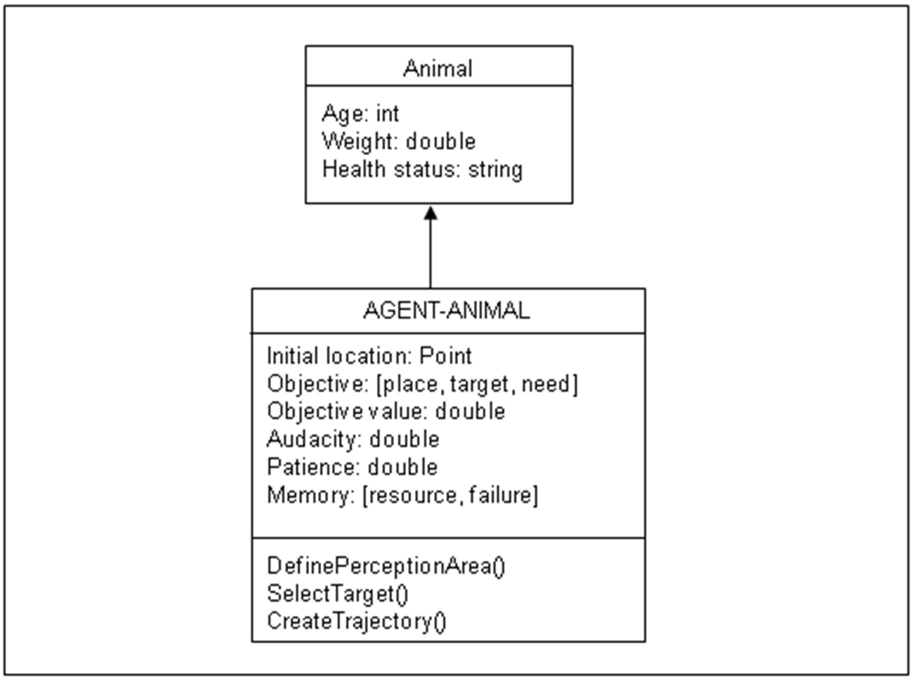

Fig. 6 Animal Agent definition

By simulating the animal movements, we want first to test behaviour parameters of the animal and second to integrate and compare the different modelling of the data corresponding to the spatial environment.

4.3 Data adaptation

The simulation of trajectories allows the visualisation of the influence of modelling choices in the movements and the spatial environment. The adaptation in the topographic data may concern the data modelling:

- The form of the objects like for a simplification of complex objects.
- The semantic information: attributes can be exploited to enrich and refine the analyses.

It also concerns data treatments such as:

- Data operations like merging objects from one table.
- Topological and graph analyses of the space for topographic elements.

Geometrical modelling choices impact on the treatments of spatial features and the analyzed or calculated trajectory, as it is illustrated in figure 7 for slope breaks. The initial data are from Plan Rhône®, dedicated to floods prevention (fig. 7 a). The specifications for the slope break elements collected in the base correspond to the precise definition of linear objects for the bottom and the two upper sides. The geometry precision is relevant for the analysis of relations between movement data and spatial environment. For managing the simulation of a trajectory, the characterization of these objects can be interpreted as a whole obstacle. This would be considered as a surface area of a certain width and length that an animal would avoid to cross (fig. 7 b).

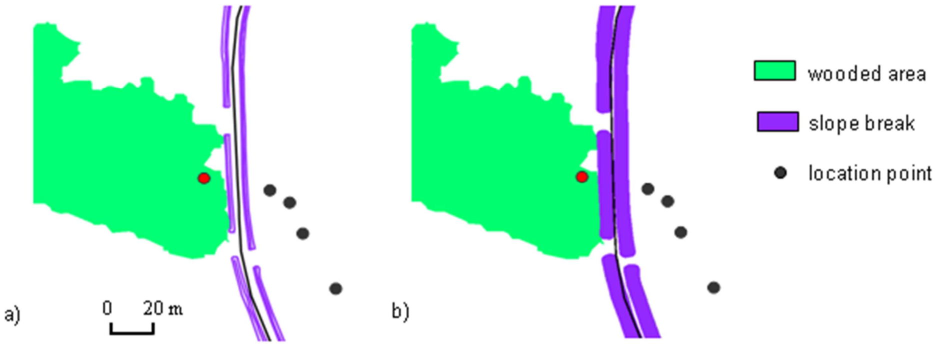

Fig. 7 Different modelling of slope breaks (data from Plan Rhône®)

a) the initial geometry b) area consideration

Another geometric modelling choice concerns merging operations of objects according to certain criteria. In figure 8, the wooded areas are represented in the BD TOPO® as surfaces. An interesting aspect in the integration of wooded areas in fauna movement studies deals with the continuity of these areas. Spatial continuity can be defined within a maximum distance limit between elements. Some object in the bases can then be associated and merged as one wooded area regarded their proximity (fig. 8 b).

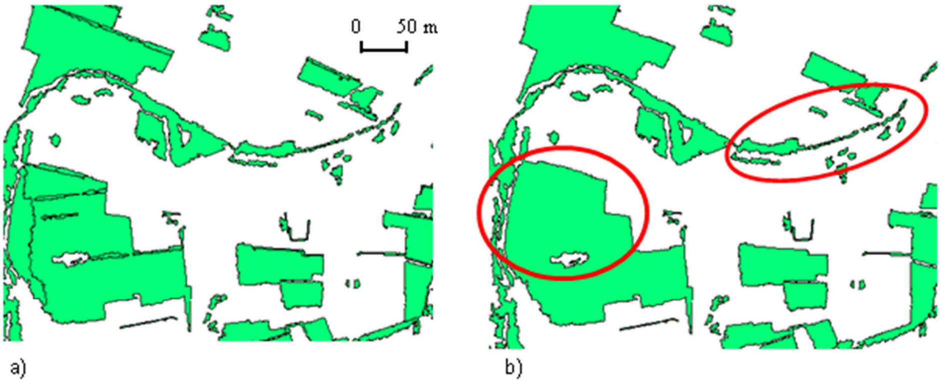

Fig. 8 Merging operations on wooded areas (data from BD TOPO®)
a) the initial data b) merged areas for continuity consideration

5 - PRESPECTIVES

We have presented a methodology to study the accurate data for animal movements' comprehension and relations to the topographic elements. It includes the analysis of the geographical area and of the trajectories, which enables to extract potential interactions. The proposed spatiotemporal model provides a way to formalize and organise the relevant concepts at stake.

As a perspective of the work, the study of different species is necessary to adjust and complete the model. Various apprehensions of the space by the species bring accuracy on the data to be selected for representing the space in animal movements. It will allow tests on different specifications on the geographical and fauna data. Depending on the availability of the data, precision, spatial scale and temporal granularity are to be defined for the type of studies.

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