Modeling risk areas for *Echinococcus multilocularis* egg survival in an urban park in France

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Abstract. *Echinococcus multilocularis* is a parasite which commonly occurs in northern temperate zones, being prevalent among wild populations of foxes. In recent years it has been reported in the suburban areas of european cities with cases of human infections. The parasite´s dispersion may be partly attributed to the increase in populations of wild foxes, their migration and adaptation to suburban environments. The probability of infection of mammals with the fox´ tapeworm *E. multilocularis* depends on the favourable alignment of a series of environmental parameters in space. intermediate The parasite life cycle includes intermediate hosts (rodents and lagomorphs) and definitive hosts (foxes and dogs?), Man can eventually be infected trough the accidental ingestion of eggs release to the environment trough the foxes´feces. This study integrates Remote Sensing images (SPOT) as a base for spatial analysis of the La Courneuve recreational park to model high risk areas of infection with *E. multilocularis* by humans and domestic pets. Thematic layers describing the important environmental parameters which may influence the prevalence levels of *E. multilocularis* and their maximum survival times were developed and integrated resulting in a suitability map identifying regions where visitors are most at risk of being infected. This area amounts to only 3.2% of the park area**.**

Key words: remote sensing, image processing, vector, habitat suitability mapping, disease prediction, risk analysis, análise de risco, parasitologia, sensoriamento remoto, mapeamento.

1   Introduction

Human alveolar echinococcosis (HAE) is a parasitic zoonosis with intermediate (rodents and small lagomorphs) and final (carnivores) hosts. The latter can transmit the parasite to humans, by their faeces, which are contaminated by the oncospheres of *E. multilocularis*, the larvae of which will develop in man´s liver like a slow cancer (Vuitton et al. 2009). The life cycle of this parasite in the wild (Figure 1), includes a fox or wolf as the definitive final host. In domestic animals, cats and dogs may harbour the parasite in their intestines with intermediate hosts being infested mice or voles. In the intestines of carnivores the parasite produces thousands of eggs which are eliminated through the faeces. Small rodents become infected while eating in contaminated areas. Once in the rodents intestine, they migrate towards the liver via the blood system and produce a fertile form of the parasite, the protoscolex. The latter is capable of becoming an adult and typically fixes itself in the intestine of a carnivorous definitive host, once it has eaten an infected intermediate host. Man may become an accidental intermediate host taking place of the rodent in this cycle. He can become contaminated by ingesting eggs of the parasite when in contact with animals infected with adult worms, such as domestic cats and dogs or by ingesting plant matter, including contaminated berries or vegetables harvested or by manipulating contaminated soil. *E.*

multilocularis eggs are very fragile to higher temperatures, but extremely resistant to cold and all known antiseptics. (Eckert, 2009).

According do Kern et al. (2003), surveillance for HAE in central Europe was initiated in 1998. Most cases originated from rural communities in regions from eastern France to western Austria. The increasing prevalence of *E. multilocularis* in foxes in rural and urban areas of central Europe and the occurrence of cases outside the AE-endemic regions suggest that this disease deserves increased attention. Having "…*analyzed databases spanning 50 years, which included retrospective alveolar echinococcosis case finding studies and databases of the 3 major centers for treatment of AE in Switzerland…*", Schweiger et al.(2007), observed "…*that the fox population increased 4-fold from 1980 through 1995…*" and this increase in the fox population and high *E. multilocularis* prevalence rates in foxes "*in rural and urban areas may have resulted in an emerging epidemic of AE 10-15 years later*".

Jenkins et al. (2005), reviewing *E. multilocularis* spread in Europe, noted that the adaptation of foxes to urban environments appeared to have coincided with rural fox population increase (Chautan et al., 2000) and that foxes were also common in many towns and cities of south-central Europe (Gloor et al., 2001). In these locations fox population densities can exceed those in rural habitats due to abundant availability of anthropogenic food (in Contesse et al., 2004), and that infection rates can be higher in cities whilst generally lower in surrounding rural areas, probably due to the limited presence of habitats suitable for voles. Transmission to man from pet dogs and cats which get infected by catching rodents in city parks and gardens is known to happen and the increasingly closer association between fox and man in urban areas is cause for concern. Schweiger et al (2007) note the increase in incidence of HAE after fox population increase. In a similar type of parasite, *E. granulosus*, Guzel et al. (2008), observed that free roaming dogs in Turkey had a higher rate of contamination than restrained dogs.
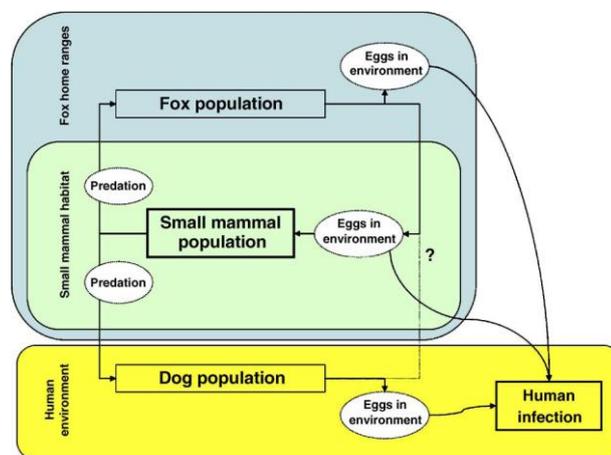
Figure 1 Conceptual model of transmission cycle of *E. multilocularis* from Danson et al (2006).

2   Remote sensing GIS and integration with zoonoses studies

Several examples of studies integrating RS and GIS are known. Graham et al. (2004), used ESRI ArcView® 3.2 GIS and its Patch Analyst© extension to analyze Landsat MSS image to classify landscape to investigate the relationship between landscape patterns and the transmission of HAE transmitted by *E. multilocularis*. The landscape use and land cover were was classified into five classes: forest, agriculture, grass, grass/shrub and tree/shrub and analysed using landscape metrics for 44 metrics potentially associated with the disease transmission. The results of the analysis was was the confirmation of their hypothesis that landscape is indeed a key spatial determinant on disease transmission to humans. The results

also enhanced the value of using remote sensing and GIS analitical capabilities as they made evident that " …*present-day prevalence values were demonstrated to be linked to landscapes of the past…*" (Graham et al.; 2004) (15 year lapse in the study).

Danson et al. (2006), reviewing "…*application of satellite remote sensing for landscape mapping, and the implementation of spatial modelling techniques to analyze landscape and epidemiological data* …" noted the application of satellite remote sensing in the context of *E. multilocularis* transmission, highlighting the advantage of mapping "… *landscape changes over the last 30 years and the potential range of quantitative information that may be extracted*…" from various source images. Some of these now come with "… *very high spatial resolution data (60 cm or less) and become routinely available, which can facilitate 'sub-patch' scale mapping of vegetation cover. Topographic data at 30 m resolution from the Shuttle Radar Topography Mission (SRTM)* …" is now available globally and can provide useful layers for integrating variables like soil moisture and solar radiation, important factors influencing parasite egg survival.

In the case of *Echinococcus* spp., Lagapa et al. (2009), used GIS Arcview 9, to produce maps relating percentage occurrences of *E. multilocularis*-positive fox faeces and land use classes, finding a positive correlation in the Nopporo Forest, an urban forest in Sapporo city, Japan. His conclusion is that "… *interface between forests, woodlands and open fields as being are indispensable for continued maintenance of E. multilocularis life-cycle and as such constitute high risk areas for echinococcoosis transmission*…". The urban forest therefore acts as a reservoir for the parasite.Conraths et al (2003) see raster representations of samples of infected foxes as an effective mapping method.

2.1 Site selection for *E. multilocularis* high contamination risk areas.

This study is based on the initial investigation of Benabderrahmane (2008) and uses a multi-thematic layer integration approach to predict risk areas with Idrisi GIS software. The layers developed were based on the best knowledge available and reclassification of these layers in function of known environmental microclimate necessary for the longest survival of the exposed parasite egg once in the open field on a fox's stool.

2.2 Study area
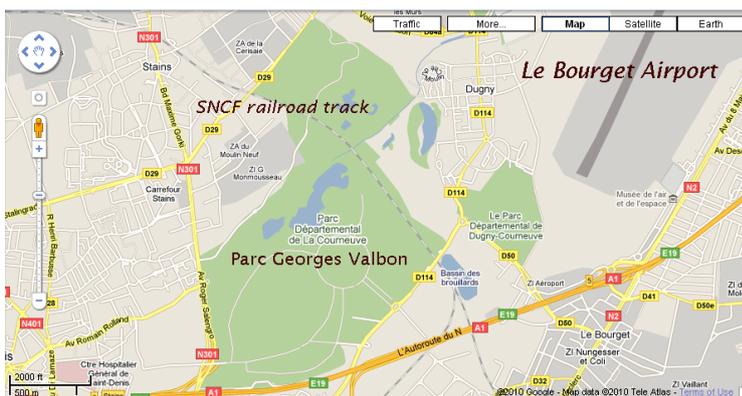
Figure 2 Distance from water bodies

The Georges Valbon park, also popularly known as the 'Parc Départemental de la Courneuve' is situated in the northwest area of Paris, within a 10 km radius of downtown Paris, France, with its center at 48°56'34.55 N and 2°24'07.86 E (WWW.ref.1). Its main geographic confrontations include the Le Bourget airport to the northeast, the A1 *autoroute* highway to the south, N301 national highway to west and D29 departmental road to the northwest. The northern part of the park is sectioned in a north/south fashion by the SNCF railway track traversing in an east-west direction. The park covers five districts: La Courneuve, Saint-Denis, Stains, Dugny, Garges-les-Gonesse (Val d'Oise). It is the largest park in the Île-de-France region of France covering 415 ha of vegetation, including playing fields with lawns, open meadows, grassland marshland, shrubland and forests. It is a 'Natura 2000' classed area. Its initial project began in 1934 and the latest renovations concluded in 2003. It is the third largest open area in the Parisian area just after the Bois de

Boulogne (1,000 ha) and the Bois de Vincennes (850 ha). Natura 2000 is a network of european sites preserving regional ecological heritage while taking into account human activities. The public walks idealized in 1934 had to wait until 1954 for the first project to be accomplished. The first landscaping began in 1960. Because of its extent, works were divided into tracts, open to the public as they became completed, the last of which includes waterfalls opened in 2003. Over 140 species of birds have been observed in the area (WWW.ref.2). Local climate is classified as continental and oceanic, as it is not too far from the Atlantic Ocean. Summer temperatures average 19.5°C, Winter temperatures at 5°C. Annual precipitation is 641.6 mm thus distributed: Summer: 52.4mm, Winter: 50.5mm. Average sunshine is 1,798 hours per year (WWW.ref.3).

Figure 3 Spot image color composite of study area

3   Materials and Methods

Figure 3 shows the study area in a color composite SPOT Image provided by the CNES (the french Centre National d'Etudes Spaciales). The park boundary is delineated as a white line. Of the 415 hectares of park area, this study analysed 384 ha.

3.1 Natural conditions:

Considering conditions usually found in natural ecosystems and environments, *E. multilocularis* eggs best chances for survival and infection of an intermediate host are under temperatures between -30 and +30 C, average relative humidity (over 60%) and up to two years after exposure (Bresson-Hadni et al., 1997). The eggs must be ingested by an intermediate host, usually a small rodent.

As these conditions are not found everywhere, the proposed hypothesis is that the best chances for tapeworm egg survival in the environment can be predicted by GIS-assisted mapping. For this, a Geographic Information System (GIS) was used to integrate field information and remotely sensed images in a logical model.

This study suggests an exploratory working model to achieve this end, and is open to comments, suggestions and contributions. Its database is derived in great part from Benabderrahmane (2008), where the infection risk for the La Courneuve Seine-Saint-Denis park was evaluated using a GIS.

4   Results and Discussion
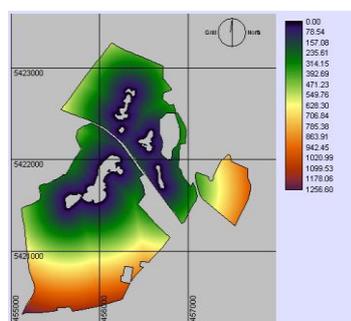
Figure 4 Distance from water bodies

4.1 Moisture content

Two aspects were considered: a) Proximity to water bodies and b) general exposure.

4.1.1   Proximity to water bodies.

Water bodies maintain locally high humidity around its perimeter. The closer to this important landscape feature, the higher the probability of worm egg survival. To obtain an image representing this characteristic the base SPOT Image was used, where water bodies were identified and digitized manually. It is
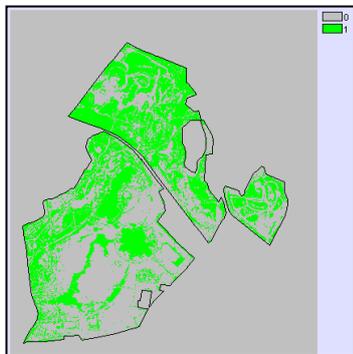
Figure 5 Grass/shrub vegetation coverage

4.1.2 General exposure

The air/soil moisture is an important factor contributing to egg viability and longevity. Open and exposed areas are less favourable in preserving mean temperature and air humidity. Thus, very open areas such as in the midst of the grassy/shrub covered areas in the park were considered less favourable than those in the forest fringe. To identify these areas, (forest covered and grassland covered) signature development on the colour composite was carried out, and extraction of all similarly covered areas, such as grassy covered areas in Figure 5. A total of approximately 160 hectares for open/ exposed grassland/ shrub covered areas was found.

4.1.3 Tree-shadow protection
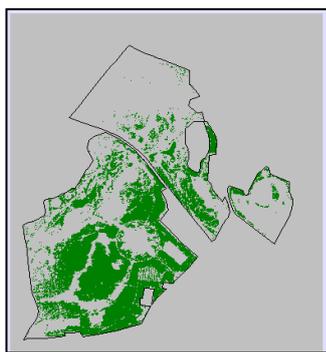
Figure 6. Forested areasareas

Protection from excessive exposure to sunlight and dessication, such as is normally the case in open areas, can be found in the shadow of trees. To determine the areas protected by tree shadows a distance image was generated from Figure 6. The fringe between forest and grassland is potentially an area of great potential for *E. multilocularis* egg preservation since it conserves lower air temperatures during the day over the soil and is also an ecotone which foxes usually use for cover and escape, i.e the open areas for hunting field mice and densely covered forested areas where they can find shelter and refuge. Figure 6 shows 130 hectares of forest-covered areas.

4.2 Fox prey availability.

Small rodents usually eat a variety of seeds, berries and small fruits. Although densely wooded areas can harbour rodent populations, in general the field mice are more frequently associated with grasslands, prairies, pastures, farmland and shrubland coverage. Prevalence of *E. multilocularis* in foxes is greater in areas with grassland (Pleydell, 2004). Open areas can potentially harbour large colonies of small rodents more so than in forests. At La Courneuve, two main types of vegetation cover can be identified. Forests and grasslands. Both are managed for the public and represent but loosely, natural types of forests, grasslands, fields. These vegetation assemblies are usually dominated by a variety of monocotyledons which provide a variety of food used by the rodents and voles including tender plant tips and small seeds. In forests, microtines usually use tree seeds and nuts. The ratio forest/land coverage in the study area is about 40/60. Areas which where food was considered more plentiful for the prey were those closer to the water bodies and closer to open grass/shrub coverage.

4.3 Potential infection sites

Although it is not feasible to map on a wide range study the point sources of *E. multilocularis* such as represented by individual stool locations, for this study, the coordinates of fox faeces found by Benabderrahmane (2008) and collaborators in the La Courneuve park

were plotted and considered as high contamination risk areas. 20% of the autopsies performed on foxes sampled at the La Courneuve park were positive for this parasite presence. This leads us to believe that faeces left by the foxes are a likely source of infection. Furthermore Girardoux et al. (2006) find that patterns of contamination are dependant of patterns of defecation and faeces distribution. This information by Benabderrahmane (2008) was used to develop a distance layer illustrated in Figure 7.

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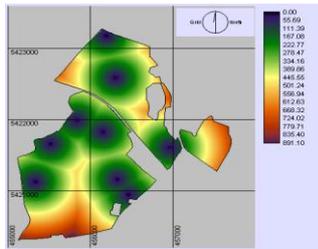
Figure 7. Distance from faeces deposits

4.3.1 Potential fox den sites

Foxes live in the proximity of their prey, and if possible, to their dens, many times located on hillsides. This gives them the maximum benefit of proximity to food resources and being able to feed their offspring and find protection. It is along this path, route or area, that they will defecate, producing the point source contamination of the tapeworm eggs. Foxes are known to take shelter in burrows on hillsides. Inclined slopes are ideal for this. To create a layer depicting these areas in the study area, an adaptation of an image created by Benabderrahmane (2008) using a digital terrain model of the park area was created (Figure 9). In this study, all areas closest to slope inclines greater than 23 degrees were considered Most Suitable for fox den building. The further away from this feature the less suitable the terrain was considered.
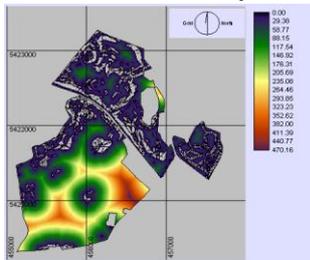
Figure 9. Distance from suitable den sites

4.3.2 Fox behaviour

A component not to be overlooked in the evaluation of site suitability for *E. multilocularis* success in infecting intermediate hosts is the behaviour of foxes. Foxes are notoriously shy, furtive animals, which avoid at all cost contact or proximity with humans or their domestic canine associates. Usually only sick or famished individuals will be bold enough to approach human settlements and habitats in search easy prey as domestic fowl. Thus, a layer depicting increasing distance from human/canine presence was developed using the as reference a) points of assembly, b) park entrances, c) car parks and d) footpaths in the park (Figure 10).
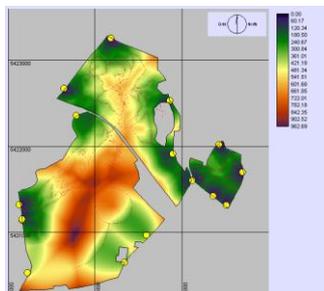
Figure 10. Distance from human/canine presence

4.3.3 Migration routes/ invasion interfaces.

Foxes tend to cover wide ranges especially during Autumn and Winter (Shaikenov, 2006). Individuals are forced to emigrate their native homelands in search of food and to eventually establish new populations elsewhere. The study area, La Courneuve, an urban park, is isolated from other tracts of land coverage with forests or grassland/pasture areas and wildlife. The main access route for foxes to enter the park seems to be the railway track which traverses the park. Although the railtrack sides are mostly fenced and walled up, closer inspection shows that in reality they offer little impediment if any to fox transit into or out of the park. Thus, an image representing proximity/distance to the railtrack was developed (Figure 11). Another potentially important fox entry point may
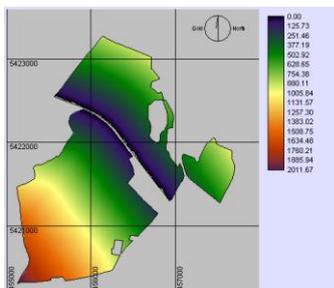
Figure 11. Distance from potential fox entry sites

be the Le Bourget airport grounds, which border the northeastern part of the park. Rabbits are found in abundance in the airport fields and probably attract foxes. However, to simplify the initial analysis of this study this frontier was not considered a significant point of fox entry.

5   Multi-criteria Evaluation
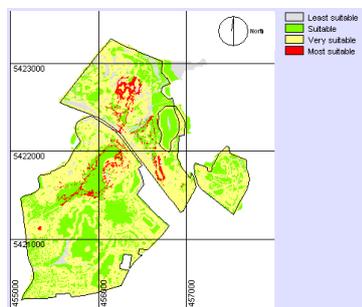
Figure 12. Site suitability for *E. multilocularis* egg survival

To evaluate the risk potential of infection, the above described thematic layers were integrated into two submodels. Submodel 1 concerned the integration of information judged to be the most favourable for the parasite's egg survival for the longest time possible: i.e. a) Proximity to water courses and bodies, b) grassy areas/open areas close to trees and c) areas not under the forest cover itself. Submodel 2 took into account the set of conditions where fox stools are most probably deposited by foxes during their activities and potentially infect an intermediate host such as rodent or other, such as a dog walking through the park with its owner. This submodel took into account: a) proximity to the locations where fox stools have been found b) the furtive behaviour of foxes which shy away from footpaths, places where humans gather such as parking lots, entry points, playing fields, c) fox habit of keeping on the border of swaths such as in forest/field interface which facilitate escape, d) potential fox den sites such as available slopes, e) probable invasion routes for newcoming foxes, such as the railroad track. Each submodel used a set of weights developed arbitrarily by the first author, and both results were integrated in a final overlay operation where only the maximum value of each was maintained. The basis for the weighted entry images in the submodels rested on reclassified images which used four classes a) 1-25m, b) 25-100m, c) 100 – 300m, d) over 300m distance criteria for fox range in the target layers. These distances were also set up arbitrarily by the first author, and may be adjusted at any time, based on better in-depth knowledge of the species behaviour, which may vary from place to place and under different forcing situations.

Infection Risk =
Submodel 1. 'Egg survival' = (waterdis*0.2583 + grassdis*0.6370 + treecover*0.1047)
Submodel 2. 'Fox presence' = (foxfaeces * 0.3681 + foxshyness * 0.0813 + maxvegdist * 0.1011 + foxdendist * 0.3489 + foxpenetration * 0.1006)

The study conlcudes that only a small fraction of the La Courneuve park actually represents a high risk area of *E. multilocularis* infection. 3.2 % Most suitable, 56.6% Very suitable, 34.1% Suitable, 6.7% Least suitable.

6   Conclusions

The model developed generalized spatial information from limited number of field samples (*n= 9*). It may be useful for researchers working along similar lines of spatial investigation of disease leading towards better understanding of the fox's behaviour could contribute to the model refinement. The predictions made by the model could not be properly validated as such would demand resources not currently available. Whereas HAE is still a very rare disease among the general population in Europe, and thus not a research funding priority yet, its progress should be followed with attention as modern culture and human activities are ever increasingly modifying the landscape. RS and GIS modelling can provide efficient means of keeping up with these changes.

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