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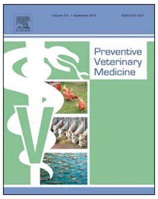

Echinococcus multilocularis management by fox culling: An inappropriate paradigm

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ABSTRACT

With the ongoing spread of *Echinococcus multilocularis* in Europe, sanitary authorities are looking for the most efficient ways of reducing the risk for human populations. Fox culling is one particular tool that has recently shifted from predation control to population health management. Our study aims to assess the effectiveness of this tool in limiting *E. multilocularis* prevalence in fox populations in France.

During four years, a culling protocol by night shooting from cars was implemented around the city of Nancy (eastern France) representing ~1700 h of night work and ~15,000 km driven. The 776 foxes killed represented an overall increase of 35% of the pressure on the fox population over 693 km^2.

Despite this consequent effort of culling, not only did night shooting of foxes fail to decrease the fox population, but it resulted in an increase in *E. multilocularis* prevalence from 40% to 55% while remaining stable in an adjacent control area (585 km^2). Though no significant change in age structure could be described, an increase in immigration and local recruitment is the best hypothesis for population resilience. The increase in prevalence is therefore considered to be linked to a higher rate of juvenile movement within the culled area shedding highly contaminated faeces. We therefore advocate managers to consider alternative methods such as anthelmintic baiting, which has been proven to be efficient elsewhere, to fight against alveolar echinococcosis.

1. Introduction

The spread of alveolar echinococcosis in Europe and the threat it represents to the human population is no longer in question, it's a fact (Romig et al., 2006; Knapp et al., 2009; Osterman Lind et al., 2011; Combes et al., 2012). Also beyond doubt is the obvious link between fox population densities, i.e. *Echinococcus multilocularis'* main definitive host in Europe, and the environmental contamination and direct or indirect human exposure to the parasite (Deplazes et al., 2004; Schweiger et al., 2007; Liccioli et al., 2015). What is at stake today is what should (or can) be done to better prevent further human infections.

The first step to protect human populations has been to develop and optimize medical tools for the diagnosis and the treatment of the disease. Today, the presence of the parasite (asymptomatic for up to 15 years) is, in most cases, discovered soon enough for the patient to receive appropriate medication (Brunetti et al., 2010; Piarroux et al., 2011). Such treatment has reduced the loss of life expectancy from 20 years (1970) to 3 years (2005), but remains toilsome for the patients and onerous for the society (Torgerson et al., 2008).

The eggs being the infective stage for humans and the only free phase of the parasite's life cycle, they may be assumed to be priority targets for the control of *E. multilocularis*. Unfortunately, their microscopic size and their extremely high resistance to humid and cold conditions such as those met in its distribution range prevent any targeted action (Veit et al., 1995). Specific public information campaigns could reduce the contact rate with the eggs by teaching safer behaviours. The real impact of such campaigns is yet very difficult to assess. As for humans, no treatment is currently available to hinder the larval stage within the intermediate hosts, most often small mammals. Moreover, considering the relatively low *E. multilocularis* prevalence in rodent populations and the overdispersion of parasite hotspots (Giraudoux et al., 2002), control options are virtually impossible and predictably ineffective in this compartment. The more promising

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strategies are then focusing on the adult stage of the parasite in red foxes.

Initially developed for the treatment of *E. granulosus* in dogs, praziquantel-based anthelmintic compounds showed very high efficiency in killing the adult worms of *E. multilocularis* in fox intestines. Relying on the successful management of vaccine distribution against rabies in the late 20th century, anthelmintic bait distribution was tested in different countries (as reviewed in Hegglin and Deplazes (2013)). In most cases, a frequent treatment (monthly, at least for an initial period) over one year or more, strongly decreased the parasite prevalence within fox populations (Tackmann et al., 2001; Hegglin and Deplazes, 2008). Yet no effective eradication of *E. multilocularis* has been described, and infection of the fox populations often recovered to pre-treatment levels within months after the end of bait distributions (Romig et al., 2007).

Raoul et al. (2003) showed that a sudden and strong fox population decrease due to indirect poisoning (as a side effect of small mammal control by anticoagulant rodenticide) led to a drastic decrease of *E. multilocularis* contamination in fox faeces. However, fox culling (gas, poison, trapping and shooting) had adverse effects on rabies epidemics in the 1990s, with culls either ineffective and unsustainable on a large scale (Morters et al., 2013). Virus transmission, believed to be directly density dependent, is apparently less complex than two host parasite transmission. Evidence of the feasibility and the effects of such protocol should thus be provided before proposing large scale fox depopulation to control and prevent alveolar echinococcosis.

In 2006, the presence of infected foxes within the city of Nancy was detected by Robardet et al. (2008), triggering concern amongst local authorities about possible human exposure. Fox culling having been suggested as a control tool, we implemented the culling program alongside a monitoring protocol to provide evidence-based information on the effectiveness of this method. We firstly tested the hypothesis that a large scale community based fox culling protocol is effective at significantly reducing fox abundance around a medium-size city. The second hypothesis tested was that the fox culling protocol would in turn induce a decrease in the presence of *Echinococcus multilocularis* within the targeted fox population.

2. Material and methods

2.1. Study area

The city of Nancy is the centre of a large conurbation of 430,000 inhabitants located in north-eastern France (48° 41′ 37″ North; 6° 11′ 05″ East). This region is a long known foci of alveolar echinococcosis (Aubert et al., 1987) with current *E. multilocularis* prevalence in fox population reaching 51.4% (Combes et al., 2012). Ranging from 188 m to 353 m of altitude, the conurbation (~15 km^2) is surrounded by a large forested area (to the west) and an agricultural mosaic of meadows/pastures and crop fields (mainly wheat, corn and colza).

The study area was a circle of 20 km radius centred on the city of Nancy (Fig. 1). It was longitudinally divided by two landscape structures, the highway A31 to the west and the river channel Marne-Rhine to the east. The northern half was dedicated to the fox culling whereas the second half (South) was kept as a control area with no change in hunting and trapping activities. A sampling grid of 3 × 3 km was set on the whole area with 77 grid cells in the North (693 km^2) and 65 grid cells in the South (585 km^2).

2.2. Fox culling

In France, fox hunting is regionally administered. In our study area, hunters were allowed to shoot foxes from June to February with no quotas. The main practices were stand hunting at dusk, scouting with or without dogs and driving/flushing the animals. In addition, foxes were classified as a “pest” allowing trapping all year round without quotas (restricted to certified trappers). Therefore, the first step of the culling protocol consisted in contacting the hunters and trappers of the culling area, asking for an increase in fox harvest. Concomitantly, as a sanitary management tool, an administrative authorization was delivered to certified persons to shoot foxes at night by driving with side spotlights. A similar authorisation was given over the control area in order to monitor this population, restricting the sampling effort to one fox per grid cell per year between October and April.

All foxes killed (hunting, trapping and night shooting) were to be brought back to the National Reference Laboratory for *Echinococcus* spp. (located within the study area), along with mention of the date and the grid cell of collection. There, each animal was weighed and sexed. As described by Ruette and Albaret (2010), we considered two age classes: juvenile (prior to first mating period) and adult as per their status on the 1st of February. The reproductive dynamics of the fox population was evaluated by two complementary variables. We firstly considered mating success as the proportion of adult females that did reproduce (presence/absence of placental scars). We also considered the number of placental scars for each active female as an indication of the annual reproductive fitness.

No restriction nor recommendation on the sex or the age were given for the culling operations and the sampling of the control area. Therefore, we consider the foxes killed each year as an opportunistic sample with a similar representativeness of each population. We can thus assume that any observed change in demographics would reflect a change of similar direction in the population.

2.3. Fox relative abundance

The classical method of monitoring fox abundance involves using spotlights from a car driving along a predefined circuit. According to Ruette et al. (2003), simple encounter rates are as effective as distance sampling protocols to monitor the relative abundance of foxes in Europe. Therefore, we measured the fox relative abundance as the total number of foxes seen along two continuous transects of 95 km in the culled area and 80 km in the control area (Fig. 1). During the four winters from 2008 to 2009 to 2011–2012, both transects were simultaneously surveyed in October, November, December and February during two consecutive nights. We kept the highest number of foxes seen between the two repetitions as the closest estimation of the number of foxes actually present along the circuit for a given survey.

Following Frey and Conover (2007), we used the killing success (number of animals killed per hour) during the night shooting operations in the culled area as an alternative/complementary way to assess the impact of the culling on the fox population. If the culling effort to remove one individual increases, this would reflect a decrease in the population (Harding et al., 2001). The night shooting operations in the control area could not be included in this dataset because they were restricted to one fox per grid cell per year.

2.4. E. multilocularis monitoring

As the prevalence of *E. multilocularis* in fox populations may vary during the year, we focused the monitoring during the winter months. Each year, from October to April, the first fox killed on each grid cell from the culled area was screened for *E. multilocularis* adult worms. This sample is then comparable with the sampling of the control area described before. The presence of *E. multilocularis* was assessed using the Segmental Sedimentation and Counting Technique (SSCT) as described in Umhang et al. (2011) and already used in large epidemiological surveys in France and Sweden (Combes et al., 2012; Wahlstrom et al., 2012). *E. multilocularis* prevalence in foxes was calculated annually in both study areas. In addition, the SSCT allowed us to evaluate the worm burden for each animal.