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# Chance and risk of controlling rabies in large-scale and long-term immunized fox populations

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The large-scale immunization of European fox populations against rabies is currently under the microscope for reducing the considerable expenditure without putting public health at risk. Empirical knowledge is inadequate to interpret the lasting sporadic incidences and, therefore, to verify the final success of the immunization campaigns. By using a proven simulation model we show that rabies can persist on a very low level in the form of spatio-temporal moving infection clusters within a highly immunized fox population. We found further: (i) the existence of a threshold after which the chance of eradicating the disease by vaccination increases clearly, and (ii) that at least six years of 70% mean immunization rate are required to guarantee a likely success.

**Keywords:** red fox; rabies; epidemiology; immunization; disease pattern; simulation

## 1. INTRODUCTION

Rabies is one of the most hazardous zoonoses in the world. In global terms up to 50 000 people are estimated to die from rabies every year (Rupprecht *et al.* 1994; Meslin 1997). In Europe rabies occurs mainly in a sylvatic cycle. Nonetheless it causes numerous human infections (108 human cases were reported between 1977 and 1990 (WHO 1990*a*)) and economic problems (Curk 1991). For approximately 20 years, considerable efforts have been undertaken to control the current epidemic using oral immunization of the main wildlife reservoir, the red fox (*Vulpes vulpes*) (Stöhr & Meslin 1996). The WHO estimates that based on modern disease control policy, rabies can be eradicated in Europe by the end of this century (WHO 1990*b*).

Eastern Germany represents one of the largest coherent vaccination areas ever treated in Europe (compare Stöhr & Meslin (1996) and Masson *et al.* (1996)). About 108 000 km$^2$ have now been vaccinated for at least five years, with aircraft being used to distribute *ca.* 18–20 vaccine-filled baits per km$^2$ in spring and autumn. This extensive strategy enables *ca.* 70% of the fox population to be continuously immunized, resulting in a drastic decrease of rabies incidence (Stöhr *et al.* 1994; Schlüter & Müller 1995; see figure 1).

Although much effort has been undertaken to reduce the substantial hazard posed to health and the environment, some sort of proof of the final success is required, not only to justify the considerable expenditure, but also to rule out the risk of a new outbreak (Stöhr & Meslin 1996). However, the final success remains uncertain despite the well-organized surveillance programme deployed in eastern Germany (89 721 foxes have been registered during the past six years, 2013 of them were rabid, see also figure 1). This uncertainty results from the unknown host population size, the flat-case detection rate, which is estimated to range between just 2% (Braunschweig 1980) and 10% (Bacon & MacDonald 1981; Schlüter & Müller 1995), and the low probability of detection of infected foxes at the end of an epidemic (Bacon 1981). Even though some regions in eastern Germany are presumably free of rabies in view of its complete regional cessation, other subareas show lasting sporadic incidences. In spite of the uncertainty of low-level persistence of rabies, the termination or at least cut back of the expensive vaccination programme is currently under discussion (Selhorst & Schlüter 1997). However, a reduced vaccination programme leaves a serious risk of a remaining persistence of the disease, which in turn could trigger a new outbreak. In addition, the increased density of foxes (Steck & Wandeler 1980; Goretzki & Paustian 1982; Voigt *et al.* 1985) would provide the basis for a new epidemic and cause a spread of the disease as dramatic or even worse as if vaccination had never been done (Schenzle 1995). For these reasons the termination of vaccination requires answers to the following questions. What is the overall risk of the potential low-level persistence of rabies in immunized fox populations, not only for one region but also for diverse biological and epidemiological settings? What are the ranges of the two main controlling variables, immunization rate and


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