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# TRANSMISSION DYNAMICS OF DOG RABIES IN MACHAKOS DISTRICT, KENYA

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*Un modèle déterministe de transmission de la rage et de dynamique de population canine a été développé pour expliquer les cas de rage observés et pour explorer l'impact de la vaccination pour le contrôle de la rage canine dans le district de Machakos au Kenya. Il y avait 4 importantes prévisions relatives à l'interaction entre la démographie canine et la fréquence de la rage en l'absence de mesures de lutte. Premièrement, il y a une densité seuil ($D_s$) d'environ 5 chiens km$^{-2}$ au-dessous de laquelle la maladie ne se maintient pas. Deuxièmement, la rage joue un rôle de facteur limitant l'accroissement de la population canine dépendant de la densité, et le degré de régulation augmente avec le potentiel de transport (T). Troisièmement, la prévalence d'équilibre de la rage est toujours relativement basse (environ 0,6 p. cent), même quand la rage diminue notablement la population canine. La quatrième prédiction majeure est que lorsque T est légèrement supérieur à $D_s$, l'incidence rabique va osciller au début pour atteindre un équilibre. Cependant, si T est largement supérieur à $D_s$, l'incidence rabique va continuer à osciller, avec des cycles de 30-40 ans.*

*Les prédictions du modèle sur l'impact de la vaccination du chien étaient très intéressantes. D'abord, le modèle prédit qu'une vaccination de 12 à 14 p. cent n'a en principe pas d'effet. Ensuite, une couverture vaccinale très élevée, supérieure à 85 p. cent serait nécessaire si le principe de campagnes annuelles de vaccination était retenu, surtout à cause de la rapide rotation de la population canine. Cependant, si la fréquence vaccinale pouvait être augmentée à 2 par an, un taux de vaccination de 45 p. cent serait suffisant pour maîtriser la maladie. Si la période de vaccination pouvait être affinée pour coïncider avec le pic d'incidence rabique, un taux vaccinal de 36 p. cent suffirait. Pour chacun de ces scénarios, une vaccination pendant au moins 3 ans après disparition de la rage serait nécessaire pour prévenir de nouveaux foyers.*

## INTRODUCTION

Rabies is still prevalent in most parts of the developing world, with approximately 4 million people in Asia, Africa, and South America receiving post-exposure treatment and over 30 000 dying after being bitten by rabid dogs (WHO, 1992). In Kenya, rabies has been common in Machakos District for at least 40 years . We have undertaken several studies in recent years to collect information on dog ecology, dog population dynamics and rabies epidemiology required to improve rabies control in this district (Kitala et al., 1993; Kitala and McDermott, 1995).

Given this baseline data, mathematical models , often quite simple ones, can serve as a useful tool for predicting disease incidence under different natural and disease control scenarios (Anderson and May, 1991) and have been used to advantage in assessing rabies epidemiology, particularly in fox populations in Europe and North America (e.g. Anderson et al., 1981; Voigt *et al.*, 1985). In this paper, we describe a simple deterministic model of rabies which incorporates both transitions between the main rabies disease states and dog populaton parameters, particularly thresholds for dog density. We compare model predictions to observed patterns of rabies in Machakos District and also explore the potential efficacy of different rabies control programmes.

## MODEL FORMULATION AND PARAMETERS

The model predicts temporal changes in rabies cases a single population, ignoring the spatial patterns of spread from adjacent populations. However, the spatial aspect of density dependence is included, since most dogs in Machakos scavenge for food (Kitala *et al.*, 1993). Dog population was modelled using a logistic model, with parameters for birth rate, death rate, dog density and population growth. Population growth was limited by an estimated habitat carrying capacity (K). Demographic parameters were estimated with data from a one year field study in Machakos District (Kitala and McDermott, 1995). To model rabies transmission, dogs were classified as susceptible (S), latent (L), infectious (I) and immune (V). The total population size N, is S+L+I+V. Transmission parameters between these states were estimated from data on rabies cases in six study villages collected over a one year period and are listed in Table I.

The rate of disease transmission, ß, is assumed to be a function of encounters between susceptible (S) and infectious (I) dogs, where 1/ß is proportional to the average time interval between dog contacts. Although there is some evidence that dogs are infective before signs of rabies are manifested (Fekadu, 1991), transmission is more likely when dogs are rabid, so it is assumed that latent and incubation periods are equal. In addition, it is assumed that dogs pass from the latent or incubation class to the infectious state at a per capita rate Õ, such that the average incubation period is 1/Õ. It is assumed in this model, that rabies is invariably fatal and that rabid dogs die at a constant per capita rate Ó where 1/Ó is their life expectancy. Susceptible dogs are vaccinated at a per capita rate Ý and it is assumed that they remain immune, since estimates of life expectancy for dogs in this

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district (Kitala and McDermott, 1995) are shorter than the duration of immunity conferred by currently used vaccines (Precausta *et al.*, 1985). Since the infection is severely debilitating and of short duration, it is assumed that only susceptible and immune individuals reproduce. We also assume that all puppies are born susceptible. Given these definitions and assumptions, a set of four differential equations describing rabies dynamics were written:

(1) dS/dt = *a*(S+V) - ßSI - *b*S - ÝS - þNS
(2) dL/dt = ßSI - (Ŏ+*b*)L - þNL
(3) dI/dt = ŎL - (Ó+*b*)I - þNI
(4) dV/dt = ÝS - *b*V - þNV,

where þ = *r*/K and is a measure of density dependent mortality due to intraspecific competition for resources, *r* is the intrinsic growth rate of the dog population and *a* and *b* are the birth and death rates of the dog population. The latent (1/Ŏ) and infective periods (1/Ó) were obtained from data by Foggin (1988) because they come from natural rather than experimental infections. All parameters are listed in Table I.

The basic reproduction ratio, $R_0$, the expected number of secondary cases produced by an infectious individual in a population of S susceptibles (Anderson and May, 1991), was estimated according to the method of Coleman and Dye (1996) using data from a rabies outbreak during our Machakos study. From the relationship $R_0$ = ŎßS/(Ŏ+*b*)(Ó+*b*) (Anderson, 1982), ß was estimated by rearranging this expression. The estimated dog population size for the district together with the estimated fraction of unvaccinated dogs (Kitala *et al.* 1993; Kitala and McDermott, 1995) were used to estimate the size and hence the density of susceptible dogs (S).

**Table I**
**Dog population and rabies parameters estimated for the Machakos District, Kenya, dog population.**

| Symbol | Variable | Estimate used |
|---|---|---|
| *b* | Per capita death rate | 0.357 $\text{year}^{-1}$ |
| *r* | Per capita population growth rate | 0.0902 $\text{year}^{-1}$ |
| a | Per capita birth rate, r+b | 0.447 $\text{year}^{-1}$ |
| K | Mean carrying capacity | 14 dogs $\text{km}^{-2}$ |
| þ | Mean degree of density dependence | 0.006 |
| ß | Transmission coefficient | 15 $\text{km}^2$ $\text{year}^{-1}$ |
| Ŏ | 1/Ŏ is the average latent period | 12 $\text{year}^{-1}$ |
| Ó | Death rate of rabid dogs | 64 $\text{year}^{-1}$ |

## RABIES INCIDENCE PREDICTED UNDER CURRENT CONDITIONS

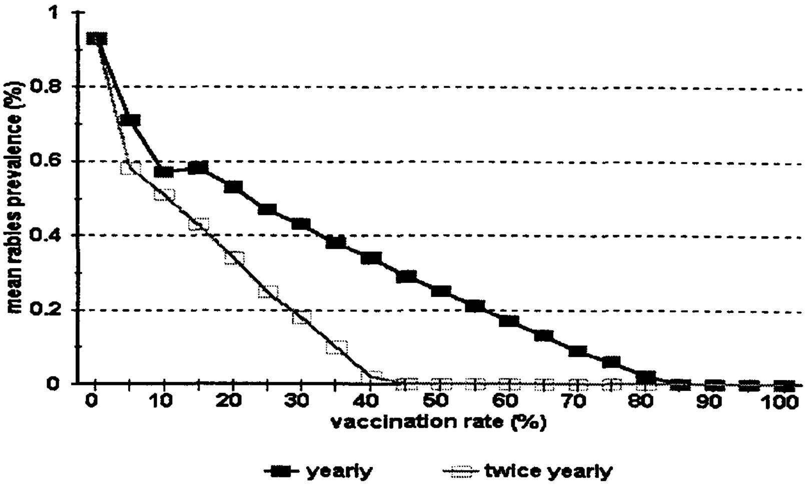
The model was formulated so that dog rabies would no persist — below a density threshold ($K_T$), where the threshold, $K_T$ = (*a*+Ŏ)(*a*+Ó)/ßŎ (Anderson *et al.*, 1981). For the values listed in Table 1, $K_T$ is 5 dogs $\text{km}^{-2}$. This threshold is supported by field data. In Tanzania, rabies is endemic in dog populations which exceed 5 dogs $\text{km}^{-2}$ but not in others having approximately 1 dog $\text{km}^{-2}$ (Cleaveland and Dye, 1995). In Zimbabwe dog rabies has persisted in communal lands with mean densities of 6 dogs $\text{km}^{-2}$ (Foggin, 1988; Brooks, 1990) but not in commercial farming areas of lower dog densities. Similarily, dog rabies in South Africa occurs in higher dog density areas and does not persist in adjacent areas with dog densities of 1-2 dogs $\text{km}^{-2}$ (Bishop, personal communication). This pattern has also been seen in fox rabies (Anderson et al., 1981; Steck and Wandeler, 1980). Thus, rabies vaccination should focus on areas of higher dog density.

In the absence of rabies control, rabies contributes to factors limiting dog population growth, when $K > K_T$. The equilibrium prevalence, measured by the proportion of dogs rabid or incubating the disease, will be low, given the relatively short duration of rabies infection. The estimated equilibrium prevalence using the parameters in Table 1 and the method of Murray *et al.*, (1986) was 0.6%. When $K > K_T$, there are two possible patterns of rabies incidence over time. If K is slightly larger than $K_T$, incidence will oscillate after introduction into a susceptible population, with the amplitude of the oscillations gradually decreasing until an equlibrium is reached. However, if K is relatively large, oscillations approach limit cycle behaviour, with cycles of 30-40 years.

## RABIES INCIDENCE WITH DIFFERENT VACCINATION PROGRAMMES

Using the parameter values listed in Table 1, the model predicts that the current annual vaccination rate of 12-14% has no impact at all in decreasing rabies incidence. Three different vaccination scenarios were tested, an annual vaccination campaign and a semi-annual vaccination programme. For an annual vaccination campaign, the current programme, vaccination coverage in excess of 85% would be required for control (Fig. 1). However, if vaccination frequency could be increased to twice per year, a vaccination rate of 45% would be adequate (Fig. 1). This dramatic difference in vaccination coverage required by increasing vaccination frequency reflects the young age and very high turnover of the susceptible dog population (Kitala and McDermott, 1995). In this population, only 50% of dogs survive to one year of age. We also investigated a vaccination programme with vaccination targeted to coincide with periods of peak rabies incidence. For this programme, the model predicts that a vaccination coverage of only 36% would suffice. The option to refine the season of vaccination has been used with success in the control of fox rabies in eastern Ontario (Wandeler et al., 1994). The model predicts that for any of these 3 scenarios, vaccination for at least 3 years post-control would be required to prevent subsequent outbreaks.

**Figure 1**
**Comparison of rabies prevalence by vaccination coverage for yearly and twice yearly vaccination**



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