A DOG RABIES VACCINATION CAMPAIGN IN RURAL AFRICA: IMPACT ON THE INCIDENCE OF ANIMAL RABIES AND HUMAN BITE INJURIES

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ABSTRACT.

Despite the availability of safe and effective rabies vaccines, the incidence of dog rabies has been increasing throughout much of sub-Saharan Africa. This paper describes a vaccination strategy that has resulted in successful control of rabies in a rural African dog population. From October 1996 to February 2001, a mass rabies vaccination programme was carried out in a rural domestic dog population of northwestern Tanzania, with a dog population density of 5-10 dogs/km². Four central-point vaccination campaigns were conducted in 72 villages with a mean interval between campaigns of 338 days (± 24 days), 319 days (± 24 days) and 456 days (± 50 days). In randomly-selected villages vaccination coverage was estimated from household questionnaires as 64.2% (n=260), 61.3% (n=705), 64.30% (n=876) and 76.1% (n=348) following each of the four campaigns respectively. Rabies incidence data were collected by active surveillance in the vaccination zone (Serengeti District) and in an adjacent control zone (Musoma District). Following the start of dog vaccination, the incidence of dog rabies declined significantly in Serengeti District and was significantly lower than in the control zone. The reported incidence of human bite injuries from suspect rabid animals declined significantly in the vaccination zone, but remained more stable in the control zone over the same period. A dog vaccination coverage of 60%-70% has thus been sufficient to control rabies in a rural African population and has led to significantly reduced demand for human post-exposure vaccine. The number of wildlife rabies cases in the adjacent Serengeti National Park increased in 1998 but declined in 1999 and 2000.

1 INTRODUCTION.

Rabies was first confirmed in Tanzania in 1934, but the disease is widely believed to be more prevalent and widespread today than at any time in recorded history. Several factors are thought to have contributed to an increase in rabies over the past three decades, including (i) the rapid growth of human and dog populations, (ii) the increasing mobilisation of rural populations, and (iii) a decline in the infrastructure and resources available for disease control (Cleaveland, 1998). Traditional approaches to dog rabies control in Tanzania include mass vaccination, movement restriction and culling of ‘stray’ dogs. However, none of these approaches has been widely effective over the past 30 years. Epidemiological theory suggests that a vaccination coverage of 70% should be sufficient to prevent outbreaks of dog rabies, based on the pattern of rabies epidemics in urban dog populations (Coleman and Dye, 1996). However, in Tanzania, the proportion of vaccinated dogs falls well below this level, with vaccination coverage from 1980 to 1991 estimated as 0.6%-4.1%, using a conservative human:dog ratio of 10:1 and dog vaccination figures from the Ministry of Agriculture (1994).

In addition to population coverage, vaccination strategies also need to consider the frequency of campaigns. This is particularly important in dog populations with high birth and death rates (such as Tan-

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Zania), because the overall population coverage will decline rapidly after a single campaign, with the risk of outbreaks occurring between campaigns. Rabies vaccinations have traditionally been carried out annually in Tanzania. However, demographic data from rural populations indicate that more frequent campaigns (every 6-10 months) are needed to maintain population coverage above the threshold required to prevent rabies (Cleaveland, 1996).

Although several studies have reported dog vaccination coverage levels achieved through different strategies of vaccine delivery (e.g. Fishbein et al., 1992; Perry et al., 1995; Matter et al., 2000; Kitala et al., 2001), there are only few empirical data correlating vaccination coverage with rabies incidence. Vaccination of 65% of dogs in urban Peru resulted in successful control of dog rabies in Peru (Chomel et al., 1988) and ERA vaccination of 30-50% of dogs in Korea led to the apparent elimination of dog rabies from 1985 to 1992 (Lee et al., 2001). However, relatively high levels of coverage among household dogs in Mexico (56% - 86%) failed to prevent an outbreak of dog rabies in the late 1980s (Eng et al., 1993). In Zimbabwe, vaccination of an estimated 10% to 50% of the dog population from 1986 to 1995 has been insufficient to control dog rabies (Bingham et al., 1999).

A further factor that has not yet been evaluated in Tanzania is the impact of wildlife hosts on dog rabies control. Throughout the world, the pattern of rabies suggests that, despite the ability to infect multiple hosts, different strains of the rabies virus are maintained by only a single host species. If this paradigm is true for Tanzania, the current evidence suggests that the domestic dog is likely to be the principal maintenance host species in the country (Cleaveland and Dye, 1995). In this case, control of dog rabies should therefore lead to the disappearance of rabies in other mammalian hosts.

This study was set up to investigate the impact of mass dog vaccination on the incidence of dog rabies in a rural area of Tanzania, in order to determine

a) the relationship between vaccination coverage and the incidence of dog rabies;

b) the impact of mass dog vaccination on animal-bite injuries in people and demand for human post-exposure treatment and

c) the impact of dog vaccination on wildlife rabies.

2 MATERIALS AND METHODS.

2.1 Study area.

Figure 1: Location of vaccination zone in Serengeti District (shaded grey) and control villages in Musoma District (shown by black circles).
The study area was the Mara Region of Tanzania, (340-350 E, 10 30'-20 10'S). The vaccination zone comprised all villages within Serengeti District, adjacent to the Serengeti National Park (Fig. 1). The control zone comprised 10 villages selected at random within Musoma District. Both the vaccination zone and control zones were part of the Midland Zone of the Mara Region, an area of relatively homogeneous landuse, with agropastoralist production systems based on livestock and cultivation of crops, such as cassava and maize (FAO/IFAD, 1995). Within the Midland Zone, human population densities ranged between 30-50 people/km² (FAO/IFAD, 1995). Preliminary estimates of dog density using the human:dog ratio indicated that the density of dogs ranged from 5-10 dogs/km² in both Serengeti District (Cleaveland and Dye, 1996) and Musoma District (Cleaveland and Kaare, 1999). In both areas, dog rabies vaccine was available only sporadically through government veterinary services. No mass dog vaccination campaigns had been conducted in either area for at least 6 years prior to the study.

2.2 Mass dog vaccination.

A mass vaccination campaign was carried out in Serengeti District from October 1996 to February 2001 under the auspices of the Ministry of Agriculture and Cooperatives (currently Ministry of Water and Livestock Development) using a village-based strategy. One to two days prior to the vaccination date in each village, livestock officers visited the village to advertise the campaign through meetings with community leaders and at primary schools. Previous experience has suggested that children are most likely to handle dogs and bring them for vaccination (de Balogh et al., 1993; Kitala et al., 2001).

On the day of vaccination, a team of four livestock officers set up a vaccination station at a central point within the village. Dogs brought to the vaccination station were registered with data recorded on the head of the household, name of dog, age, sex, and previous vaccination history, and for females, reproductive histories. Each dog was given 1ml Nobivac Rabies vaccine (Intervet) and 1 ml Puppy DP (Intervet) subcutaneously, with the rabies vaccine being used as solvent for the canine distemper and canine parvovirus vaccine. A vaccination certificate was given, and coloured plastic collar fitted to each vaccinated dog. Vaccination was free of charge.

The first campaign was conducted between October 1996 and March 1997. Between September 1997 and August 1998, villages were re-visited in approximately the same sequence as the first campaign with the aim of vaccinating pups born since the previous campaign and any other unvaccinated adults. Previous studies have demonstrated that the life expectancy of Serengeti District dogs (1.9 years; Cleaveland, 1996) is less than the duration of immunity afforded by the vaccine (3 years). Thus we assumed that, on average, one dose of vaccine would be sufficient to protect each dog. Although advertising for the campaign targeted unvaccinated dogs, vaccinated dogs brought to the station received booster rabies vaccinations.

A third campaign was conducted between February 1999 and September 1999 and a fourth campaign between May 2000 and February 2001, adopting the same protocol as previous campaigns.

2.3 Vaccination coverage.

Vaccination coverage was determined in each phase of the campaign by questionnaire surveys of householders in randomly-selected villages within the vaccination zone. During the first campaign, vaccination coverage was also assessed by

i. direct observation of collared dogs seen in the village during the questionnaire surveys and

ii. number of vaccine doses administered in relation to the estimated total dog population.

Questionnaires were conducted within 2 days of the vaccination campaign and households sampled by systematic stratified sampling. Households were visited within each kitongoji (administrative subdivision) and one in three households sampled systematically within each kitongoji along a transect at a random bearing from the main road. This ensured that households were visited at a range of distances from the location of the vaccination station in the village centre. To assess whether samples were representative of the village as a whole, all households were visited in two of the study villages and data were compared from households in the sampling frame and from all other households within the village. For validation of questionnaire data, data on dog ownership were also compared for households in which dogs were directly observed and those in which owners reported the number, age and sex of dogs.
The dog population size was estimated from the human:dog ratio obtained from questionnaire surveys, with the village human population based on 1988 human census data with a projected regional population growth rate of 2.9% per annum (Bureau of Statistics, 1991).

2.3.1 Incidence of dog rabies.

Although rabies is a notifiable disease in Tanzania, it is widely recognized that most cases of dog rabies are not reported to the government veterinary services. To obtain more detailed incidence data on dog rabies, community-based active surveillance measures were implemented within 15 randomly-selected villages within the vaccination zone and in each of the 10 control villages, using methodology adapted from studies in rural Kenya (Kitala et al., 1994). Livestock field officers stationed in each of the monitoring villages were paid to complete monthly report forms, in which standardised information was collected from village leaders, primary school teachers and medical dispensary staff about any suspect cases of rabies in the village. In addition, a financial incentive was offered to field officers for collection of brain stem samples collected from dog carcasses, using World Health Organization collection kits (Barrat and Blancou, 1988). During the first two years of the programme, incentives were paid for all dog samples retrieved. During the third year, when rabies was reported at only very low levels, attempts were made to increase the chances of detecting cases by offering an increased incentive to be paid only when samples were confirmed rabies positive on laboratory diagnosis.

The incidence of dog rabies was recorded for each month as the number of suspect cases divided by the estimated dog population within the study villages. The dog population size was estimated from the human:dog ratio obtained from questionnaire surveys, with the village human population based on 1988 human census data with a projected regional population growth rate of 2.9% per annum (Bureau of Statistics, 1991).

2.3.2 Incidence of human bite injuries.

Animal bite injury data were collected for the vaccination and control zones from Government District Hospitals in Mugumu, Musoma and Tarime Districts. Information was obtained on the species inflicting the bite wound, the age, sex and village of origin of the victim, whether the animal was suspected of suffering from rabies and whether post-exposure rabies vaccine had been administered. Incidence data were recorded as the monthly per capita incidence of bite injuries, using human population data based on 1988 government census with a projected population growth rate of 2.9% per annum (Bureau of Statistics, 1991).

2.3.3 Wildlife rabies.

Surveillance of wildlife rabies in the Serengeti was carried out by the Tanzania National Parks Veterinary Department, using a reporting network established among park staff, scientists and tour operators. Wherever possible, brain stem samples were collected from all wild carnivore carcasses using WHO collection kits (Barrat and Blancou, 1988). Rabies diagnosis was conducted at the WHO rabies collaborating centre, Agence Française de Sécurité Sanitaire des Aliments, Nancy, France and at the Onderstepoort Veterinary Institute, South Africa, using immunofluorescence diagnostic tests (Kaplan and Koprowski, 1973). Animal cases were classified as suspect rabies if the reported history included abnormal behaviour in combination with neurological signs and/or unprovoked aggression.

2.3.4 Data analysis.

An autocorrelation analysis was carried out (Sokal and Rohlf, 1995), which demonstrated that the incidence data for dog rabies cases and dog bite injuries were significantly autocorrelated. To avoid biases arising from autocorrelated data and as a preliminary step in data analysis, non-parametric statistics were adopted to investigate differences between proportions (chi-squared test) and the difference between the median incidence in vaccination and control zones at different stages of the programme (Mann-Whitney U Test) (Siegel and Castellan, 1988).
3 Results.

3.1 Vaccination coverage prior to start of campaign.

Vaccination coverage prior to the start of the campaign was 9.1% (total dogs=4457) in the vaccination zone, and 8.5% (total dogs=316) in the control zone.

3.2 Vaccination coverage – Questionnaire survey.

Questionnaire data were collected from 1515 households from 22 villages. Over the four campaigns, the average vaccination coverage for the entire dog population was 63.7% (n=1904), with 69.9% (n=1668) adults vaccinated and 33.4% (n=326) pups less than three months of age vaccinated. Details of vaccination coverage following each campaign is shown in Table 2.

Table 6: Summary household information from questionnaire survey conducted after each campaign.

<table>
<thead>
<tr>
<th>Campaign</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dogs</td>
<td>315</td>
<td>693</td>
<td>861</td>
<td>120</td>
<td>1989</td>
</tr>
<tr>
<td>Total people</td>
<td>2048</td>
<td>4145</td>
<td>5063</td>
<td>724</td>
<td>11980</td>
</tr>
<tr>
<td>Human:dog ratio</td>
<td>6.50</td>
<td>5.98</td>
<td>5.88</td>
<td>6.03</td>
<td>6.02</td>
</tr>
<tr>
<td>Households sampled</td>
<td>226</td>
<td>548</td>
<td>674</td>
<td>101</td>
<td>1549</td>
</tr>
<tr>
<td>Dogs per household</td>
<td>1.39</td>
<td>1.26</td>
<td>1.28</td>
<td>1.19</td>
<td>1.28</td>
</tr>
</tbody>
</table>

Table 7: Vaccination coverage of the owned dog population determined from household questionnaire surveys conducted after each of the vaccination campaigns. The total number of dogs and households refers to only those households for which age classes and vaccination status of dogs was recorded and hence differs slightly from Table 1.

<table>
<thead>
<tr>
<th>Campaign</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Households sampled</td>
<td>197</td>
<td>552</td>
<td>688</td>
<td>89</td>
<td>1526</td>
</tr>
<tr>
<td>Total dogs</td>
<td>225</td>
<td>702</td>
<td>879</td>
<td>98</td>
<td>1904</td>
</tr>
<tr>
<td>Total pups (&lt; 3 months)</td>
<td>49</td>
<td>139</td>
<td>117</td>
<td>21</td>
<td>326</td>
</tr>
<tr>
<td>All dogs vaccinated</td>
<td>142</td>
<td>429</td>
<td>566</td>
<td>75</td>
<td>1212</td>
</tr>
<tr>
<td>Pups vaccinated</td>
<td>11</td>
<td>52</td>
<td>36</td>
<td>10</td>
<td>109</td>
</tr>
<tr>
<td>Overall coverage (%)</td>
<td>63.11</td>
<td>61.11</td>
<td>64.39</td>
<td>76.53</td>
<td>66.28</td>
</tr>
<tr>
<td>Coverage for adults/juveniles (%)</td>
<td>74.43</td>
<td>66.96</td>
<td>69.55</td>
<td>84.42</td>
<td>73.84</td>
</tr>
<tr>
<td>Coverage for pups (%)</td>
<td>22.45</td>
<td>37.41</td>
<td>30.77</td>
<td>47.62</td>
<td>33.56</td>
</tr>
</tbody>
</table>

3.3 Vaccination coverage - Observation of collared dogs.

Following the first campaign, observations were made of 270 dogs roaming free within three villages, of which 109 (62.1%) were wearing plastic collars that had been fitted during the vaccination campaign.

3.4 Vaccination Coverage - Number of dogs vaccinated.

The total population of owned dogs was estimated as 12,143 (95% C.I =10,766-13,512) from the human:dog ratio (Table 1) and projected human population sizes (Bureau of Statistics, 1991). During the first campaign, it became apparent that many dogs were not registered at the vaccination station, therefore the number of dogs recorded in the first campaign (5469) was considered to be an underestimate of the true number vaccinated. We therefore estimated vaccination coverage from the total
number of vaccine doses administered, assuming 2% wastage for dogs that required repeat injections due to incorrect administration (observed during subsequent campaigns). During the first campaign, a total of 7600 doses of vaccine were administered in Serengeti District, from which we estimate that a total of 7448 dogs were vaccinated, giving an estimated overall population coverage of 61.3% (55.1% – 69.2%). During the second and third campaigns, vaccines were administered only to dogs that had been registered. A total of 7552 and 6399 dogs were registered during the second and third campaigns respectively. Previous vaccination status of dogs recorded in 45 villages (n=5804 dogs) was estimated to be 27.7% overall in the second and third campaigns.

3.5 **Intervals between campaigns.**

The mean interval between successive campaigns in villages within the vaccination zone was 338 days (+24 d), 319 days (+24 d) and 456 days (+ 50 d).

3.6 **Evaluation of sampling method.**

For the two villages in which all households were sampled, the percentage of dogs vaccinated in households within the sampling frame (53.03%, n=122) was not significantly different from the percentage vaccinated in all other households in the village (54.47%, n=246). In these groups, there was no significant difference in the number of people per household ($\chi^2 = 1.06$, p>0.05), nor in the number of adult ($\chi^2 = 4.16$, p>0.05), juvenile ($\chi^2 = 0.70$, p>0.05) or pups ($\chi^2 = 0.69$, p>0.05) per household. There were also no significant differences between the number of dogs ($\chi^2 = 2.25$, p>0.05), juveniles ($\chi^2 = 0.14$, p>0.05) or pups per household ($\chi^2 = 0.63$, p>0.05) in families in which dogs were observed directly by the interviewer and those in which the number of dogs was reported by the owner.

3.7 **Rabies recognition.**

Rabies was confirmed by laboratory diagnosis in 68% (n=25) of the domestic dog cases reported as suspected rabies cases. Due to the relatively small number of carcasses retrieved throughout the study, incidence data are subsequently reported here in terms of reported cases.

3.8 **Incidence of dog rabies.**

The incidence of dog rabies is shown for the vaccination and control zones in Fig. 2. The incidence of dog rabies was significantly lower in Serengeti District in phase 2 after the first campaign (July 1997 to Jun 1998) than in phase 1 (September 1996 to June 1997) ($W_{0.25}=216.0$, p<0.001). In contrast, the incidence of dog rabies in Musoma District did not differ significantly between phase 1 and phase 2 ($W_{0.25}=100.0$, p>0.05). No cases of dog rabies were reported in any of the study villages after July 1998, while cases continued to be reported in study villages of Musoma District.

Fig. 3 gives the monthly incidence of dog rabies in the whole of Serengeti District, showing that only few cases were reported after July 1998. However, the disease was not completely eliminated with sporadic cases reported throughout that period. Due to difficulties in procurement of vaccine in early 2000, the interval between the third and fourth campaigns was longer than planned. Two cases were reported in December 2000 and a single case in February 2001. No cases have been reported since that time until the time of writing (December 2001).
Figure 2: Incidence of reported canine rabies cases monitored by active surveillance in study villages of Serengeti (vaccinated) and Musoma (unvaccinated) Districts. Active surveillance in Musoma District ended in June 1999.

Figure 3: The monthly incidence of dog rabies (shown by the black line) in Serengeti District overall in relation to the number of dogs vaccinated (shown by the bars).

3.9 Incidence of human bite injuries.

The incidence of dog bite injuries from suspected rabid dogs (shown in Fig. 4) was significantly lower in Serengeti District after the first campaign (phase 2 - July 1997 to April 2000) than before the end of the first campaign (phase 1 - November 1993 to June 1997) \( (W_{42,32}=2144, p<0.001) \). Although, the incidence of suspected rabid dog bite injuries was higher in Musoma District in phase 2 than in phase 1, the difference was not significant \( (W_{18,46}=549, p>0.05) \).
3.10 Cases of wildlife rabies.

Between August 1996 and December 2000, samples were submitted for rabies diagnostic tests from 94 wildlife carcasses from the Serengeti National Park and surrounding areas (Figure 5).

Figure 5: Number of samples submitted for rabies diagnosis from wildlife species in the Serengeti ecosystem.
The species distribution of suspected and confirmed rabies cases is shown in Table 3. Bat-eared foxes comprised the greater proportion of confirmed wildlife rabies deaths (53.8%).

**Table 8**

<table>
<thead>
<tr>
<th>Species</th>
<th>Confirmed</th>
<th>Unconfirmed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bat-eared fox</td>
<td>7 (53.8%)</td>
<td>4 (36.4%)</td>
</tr>
<tr>
<td>Spotted hyena</td>
<td>0</td>
<td>4 (36.4%)</td>
</tr>
<tr>
<td>Jackal (species not specified)</td>
<td>2 (15.4%)</td>
<td>2 (18.2%)</td>
</tr>
<tr>
<td>Black-backed jackal</td>
<td>1 (7.7%)</td>
<td>0</td>
</tr>
<tr>
<td>Wild cat</td>
<td>1 (7.7%)</td>
<td>0</td>
</tr>
<tr>
<td>Aardwolf</td>
<td>1 (7.7%)</td>
<td>0</td>
</tr>
<tr>
<td>Civet</td>
<td>1 (7.7%)</td>
<td>0</td>
</tr>
<tr>
<td>White-tailed mongoose</td>
<td>0</td>
<td>1 (9.1%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>13</td>
<td>11</td>
</tr>
</tbody>
</table>

The total number of reported cases increased following the first dog vaccination campaign, but declined in 1999 and 2000 (Fig. 6).

**Figure 6:** Monthly number of suspected rabies cases in dogs (Serengeti District) and wildlife (Serengeti National Park) reported on the basis of clinical signs.

### 4 Discussion.

Two key conclusions arise from this study. First, control of dog rabies in some rural Africa communities is feasible through implementation of a simple central-point dog vaccination strategy. Second, vaccination of dogs not only reduces the incidence of dog rabies, but also the demand for human post-exposure treatment in these communities.

In this study, vaccination of 64% of owned dogs resulted in a significant reduction in the incidence of dog rabies. While epidemiological theory predicts that a 70% coverage should be sufficient to prevent rabies outbreaks (Coleman and Dye, 1996), this study demonstrates that vaccinating 64% of owned dogs is sufficient to control endemic disease in rural African populations, with virtual elimination of rabies in the core vaccination zone. Although a few cases were reported sporadically after the second campaign (post July 1998), these cases occurred mainly at the margins of the vaccination zone, possibly as a result of transmission from unvaccinated dogs outside the vaccinated area.

A common misperception in rural Africa is that a large proportion of the dog population comprises ownerless ‘stray’ dogs. In this study, we conclude that the number of ownerless dogs is relatively insignificant because estimates of vaccination coverage obtained from questionnaire data were broadly similar to those obtained for the overall population using direct observation of collars. However, it must be noted that direct observations of collared dogs were limited in terms of the number of villages sampled, the duration of the observation periods and the lack of night observation (when free-roaming dogs are more likely to be active). More robust methods (e.g. Matter *et al.*, 2001) may be needed to provide reliable estimates of the true fraction of ownerless dogs that are inaccessible for vaccination.
Nonetheless, even if a large number of ownerless dogs have been missed in our estimate of vaccination coverage, the empirical observation remains valid that vaccinating 64% of owned dogs at 10-15 month intervals resulted in control of dog rabies in these communities.

Although central-point campaigns proved to be a simple and effective strategy for vaccinating rural dogs in this part of Tanzania, care needs to be taken when extrapolating to other parts of the country and elsewhere in Africa. For example, cultural attitudes towards handling of dogs is known to affect the accessibility of dogs to parenteral central-point vaccination campaigns in Ethiopia (Karen Laurenson, pers. comm.). Similarly, dogs sampled during a previous study in Pemba, Tanzania (a predominantly Moslem community) (Cleaveland et al., 1999) were more difficult to handle than dogs from the Mara Region, which is predominantly Christian. This study was carried only in village communities and it is highly likely that dog ownership and accessibility patterns will differ in large urban communities, affecting the coverage levels that can be attained using a central-point strategy. Further work may be needed to investigate the cost-effectiveness of different delivery methods (e.g. house-to-house, oral vaccination strategies) in other parts of Tanzania.

Rabies surveillance in both human and animal populations remains an enduring problem throughout much of sub-Saharan Africa, making it difficult to evaluate epidemiological trends, assess the true burden of disease or determine the impact of any control measures. Active surveillance measures introduced in selected villages in the vaccination and control zones allowed us to compare the incidence of dog rabies in the two populations with reasonable accuracy. However, due to the relatively short time-frame of the project, active surveillance measures were introduced only at the time that dog vaccination was initiated and pre-vaccination base-line data for the two zones are not available. Although active surveillance is highly effective in increasing rabies detection rates (Kitala et al., 1994), these measures are expensive and require intensive input, which raises doubts about sustainability for rural Africa (Cleaveland et al., 1999).

In previous studies, we have shown that animal-bite injury data provide a valuable and accessible source of epidemiological data for quantifying human rabies mortality in Tanzania (Cleaveland et al., in press; Cleaveland et al., this vol). Here, hospital records of bite injuries from suspected rabid animals also proved to be of great value as data from both districts were available for several years prior to the onset of dog vaccination, allowing trends to be monitored before and after the dog vaccination campaigns and incidence to be compared between vaccinated and non-vaccinated communities.

An important finding of this study was the rapid decline in demand for human post-exposure treatment (PET) vaccine within 18 months of the onset of mass dog vaccination, which has important implications for the economics of rabies control. Although this might be expected as a logical consequence of a reduction in dog rabies, use of human PET vaccine has not declined in several other countries following implementation of dog vaccination programmes. For example, in Tunisia, although the incidence of dog and human rabies declined by over 50% in the three years following the onset of large-scale dog vaccination in 1992, human PET remained at the same or slightly higher levels (data for Tunisia from Rabnet, oms.b3e.jussieur.fr/rabnet). Similarly, in Thailand, an 80% decline in the number of confirmed animal cases was reported from 1987 to 1996 following mass vaccination of dogs and cats (Mitmoonpitak et al., 1998). However, over the same period, the number of people receiving PET increased from 84,178 cases in 1987 to 160,448 in 1994, stimulated by public education campaigns and greater availability of vaccine (Mitmoonpitak et al., 1998). In our study, human rabies vaccine was provided by the project to district hospitals in both the vaccination and control zones from 1997 to 1999. Increased availability of vaccine might therefore explain the increase in animal-bite injuries recorded in 1997 in Musoma District, but it cannot account for the marked differences observed between the two areas after implementation of dog vaccination (Fig.4). One explanation why a decline in demand for PET was observed in our study and not in Thailand or Tunisia may be that dog rabies needs to be virtually eliminated before a reduction in demand for PET becomes apparent. Furthermore, the community needs to become aware that rabies has disappeared, which has indeed occurred very quickly in the Serengeti study. Conversely, if dog rabies is still widespread, albeit at a low incidence, the bite from any dog could still be considered a rabies risk requiring continued high usage of human PET. We suggest that there may be a threshold incidence of dog rabies incidence which must be reached before PET demand declines, and this may be a critical factor in the economic evaluation of any dog vaccination programme. Additional data from other countries and regions would be of tremendous interest in this respect.

After four years of dog vaccination campaigns in the Serengeti, the impact on wildlife remains equivocal. There was clearly no immediate decline in wildlife rabies corresponding to the decline in dog ra-
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Rabies control

bies in 1998 and 1999. However, since June 1999 only few suspected wildlife cases have been reported and none confirmed by laboratory diagnosis. There are several interpretations that are consistent with these results:

a) wildlife rabies is maintained independently of domestic dogs (possibly within a bat-eared fox reservoir population) and cycles of dog and wildlife infection occur asynchronously;

b) wildlife rabies is driven by dog rabies, but with a lag period of 1-2 years (a pattern that is consistent with temporal trends from Zimbabwe, for example – Cleaveland and Dye, 1996);

c) wildlife cases continue to occur as a result of transmission from a reservoir population of unvaccinated dogs living adjacent to the southwestern boundaries of the park, where dog rabies is still endemic. At present, each of these scenarios remains a possibility and work is currently underway to explore this further by extending the zone of vaccination to include the entire southwestern boundary of the park over the next five years and monitoring the temporal and spatial patterns of rabies in dog and wildlife populations.

Although fewer wildlife samples were submitted in 1999 for rabies diagnosis and fewer suspected wildlife cases reported, this is unlikely to be the result of reduced disease surveillance. Indeed, wildlife disease surveillance has probably been improving progressively in the Serengeti since the establishment of the Tanzania National Parks (TANAPA) veterinary unit in 1996, with park rangers, scientists, and tour operators becoming increasingly aware of the importance of reporting suspected cases.

In summary, a central-point strategy for mass vaccination of dogs provided a simple and effective method of controlling dog rabies and led to a significant reduction in demand for human post-exposure rabies vaccine in northwestern Tanzania.

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