

Rabies control in rural Tanzania: Optimising the design and implementation of domestic dog mass vaccination programmes

By

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Declaration

I hereby declare that the research described within this thesis is my own original work and has not been submitted for a degree award or any other professional qualification in any other University.

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*“The greatest glory in living lies not in never falling,
but rising every time we fall” (Nelson Mandela)*



Rabies in dogs has been known from ancient times and early prevention measures already edicted in France in the 14th Century by Gaston Phoebus (1390).

Dedication

Dedicated to my parents Dorcas Nyamata and Timothy Kaare for their immense sacrifice in making sure that I get education and my late brother Dr. Bwire Kaare for her consistent moral support and encouragement

Abstract

Rabies is an ancient zoonotic disease that still persists as significant public health problem affecting largely poor and marginalized people in poor countries of the developing world. The disease is also a cause of substantial wildlife conservation concern and an economic burden to governments where it occurs. However, the disease is grossly under-reported in most developing countries, with the result that the burden of the disease is widely under estimated and rabies perceived to be an insignificant problem. Although human rabies is completely preventable, through vaccination of animal reservoirs and post-exposure prophylaxis (PEP) of people exposed to the virus, no effective large-scale control of rabies has been achieved in sub-Saharan Africa in the past 30 years and information is still needed to optimise and sustain dog vaccination programmes. In Chapter 2, data obtained through a mass domestic dog vaccination campaign in northwest Tanzania are used to investigate strategic factors that influence the design and effectiveness of domestic dog rabies vaccination campaigns in rural Africa. The findings of this study show the feasibility of controlling rabies in a wide range of agro-pastoral socio-economic settings in rural Tanzania through central point based vaccine delivery approach and demonstrate that the use of combined central point and community-based animal-health workers (CAHWs) offers an effective alternative to central point approach as a vaccine delivery strategy in remote and dispersed pastoral communities. In Chapter 3, the economic burden of rabies at the household level is evaluated; the study demonstrates that rabies is a substantial economic concern to households in rural

Tanzania, disproportionately affecting households with low socio economic status. It is also shown that dog bite victims with low socio economic status are at higher risk of dying from rabies. The *per capita* cost for dog vaccination and potential benefits of domestic dog vaccination in agro-pastoral and pastoral communities are estimated in Chapter 4. The per capita cost for central point dog vaccination is estimated as \$1.73 and 5.56 in the agro- pastoral and pastoral communities respectively. The study also shows that rabies control through domestic dog vaccination will results in substantial net benefits to the public health sector. In Chapter 5, using both cross sectional and longitudinal data, the impact of multivalent vaccination of domestic dogs against rabies, canine distemper, canine parvo virus and canine hepatitis virus on the demography of the dog population is investigated over two consecutive years, demonstrating a significant increase in survival and dog population growth in vaccinated dogs (vaccination zone) in comparison with unvaccinated (control zone) dog populations in adjacent areas. In Chapter 6 the study demonstrates a substantial decline in incidence of human and animal rabies as a result of dog vaccination. However, despite a decline in reporting of animal rabies cases and human bite injuries from suspected rabid dogs, use of PEP at district hospitals did not decline. In Chapter 7 data from previous chapters are used to parameterise a spatially explicit stochastic model to theoretically explore the optimal design of domestic dog mass vaccination campaigns in rural Tanzania. The results of the model demonstrate that inter-vaccination interval and vaccination coverage are likely to be critical factors in designing domestic dog mass vaccination programmes in rural Tanzania. In Chapter 8 the implications of the findings in previous chapters are discussed to show that

rabies control is economically and logistically feasible in Tanzania and a multi sectoral approach to rabies control is proposed as a way forward for the country.

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List of abbreviations and acronyms

AIDS	Acquired immune deficient virus
ARV	Anti-rabies vaccine
CAHW	Community Animal Health Worker
CDV	Canine distemper virus
CHV	Canine hepatitis virus
CP	Central point
CPV	Canine parvo virus
DALY	Disability adjusted Life Years
DFID	Department for International development
EPI	Expanded Programme on Immunization
GPS	Geographical position system
HH	House to house
HIV	Human immune deficient virus
IAPSO	Inter-Agency Procurement Services Office
IRS	In house Residual Spraying
ITN	Insecticide Treated Nets
IU	International units
Kg	Kilogramme
LGCA	Loliondo Game Controlled Area
MDA	Maternal derived antibodies
MDG	Millennium development goals
NCAA	Ngorongoro Conservation Area authority

NTO	Nerve tissue origin
PreP	Pre-exposure prophylaxis
PEP	Post exposure prophylaxis
R_0	Basic reproductive number
RIG	Rabies Immunoglobulin
RRV	Rabies Related Viruses
RRA	Rapid Rural Appraisal
S	Susceptible
I	Infected
TZS	Tanzania Shillings
UK	United Kingdom
UNDP	United Nations Development Programme
USA	United States of America
WHO	World Health Organization

Chapter I: General introduction

1.0. Historical perspective of rabies

Rabies is an important infectious zoonosis that has attracted attention and fear since the beginning of recorded history, with outbreaks of rabies described throughout the course of civilization. Rabies was documented in Mesopotamia and Egypt around 2300 BC (Blaisdell, 1994), described in the Bible and other ancient literature and has been recognized throughout the world as one of the earliest diseases of mankind. The historical perspective of the disease has been extensively reviewed elsewhere (Steel *et al.*, 2004) with the disease being documented by many individuals including Aristotle and Hippocrates, who noted a connection between human infection and bites from “mad” dogs (Neville, 2004).

Over time rabies appeared in animal and human populations on every continent except Antarctica and Australia. Australia and the United Kingdom (UK) considered rabies free, have now reported human deaths due to bat transmitted *Lyssaviruses* (McCormack & Allworth, 2002; Fooks *et al.*, 2003) highlighting the need for continued vigilance and strict control measures even in countries that have been considered rabies free for very long periods.

Pasteur in 1885 was, for the first time, able to successfully provide PEP for a nine year old boy Joseph Meister who was bitten by a rabid dog, using dried virus grown in rabbit spinal cords (Hoenig, 1986). This was a legendary milestone in the treatment of infectious diseases and marked an important historical revolution in the development of animal rabies vaccine and human PEP. The period before Pasteur’s discovery was largely characterized by attempts to treat the disease using medicines prepared from animals, such as ground jaw bone of a dog, dried tongue of newly

borne colt, copper from an English penny minted during the reign of George I, wound cauterization and insertion of hairs into bite wounds (Wilkinson, 1977; Fischer, 1977; Everaerts *et al.*, 1988; Rosner, 1974). The historical rabies treatment in human is similar to current “traditional” means of rabies treatment which are still practiced to date in some parts of rural Tanzania (M.Kaare pers. observ).

PEP progressed through various modifications of Pasteur’s crude nerve tissue vaccine to phenol-inactivated rabies virus up until 1977, with wide-scale use of rabies vaccines of Nerve Tissue Origin (NTO). Despite substantial improvement on these NTO vaccines, these first generation vaccines still pose a great risk to human and are now considered unsafe for PEP since they are likely to contain residual live virus which can be infective to patients. In India for example the use of NTO vaccines has been associated with neuro-paralytic reactions at a rate of 1 in 200 patients (Arya, 1991). In addition, this method of PEP, involves a prolonged (due to low antigenic content) and painful immunization course of up to 14 injections and the treatment has been associated with a high rate of patient dropout, likely to increase the risk of death from dog bite victims (Hemachudha, 1989;Perez & Paolazzi, 1997).

More effective and safer rabies vaccines are those produced in cell cultures which are now regarded as the gold standard for rabies pre-exposure prophylaxis (PreP) and PEP (World Health Organization, 1992). Although these second generation vaccines have been available for a long period, a substantial number of PEP against rabies is still performed with vaccines of nerve-tissue origin particularly in the developing

countries where the more expensive but effective and safer cell culture vaccines are not affordable (World Health Organization, 1992; Fischer, 1995).

1.1. Rabies: the disease and aetiology

Rabies is acute encephalitis caused by the virus in the genus *Lyssavirus*, family *Rhabdoviridae*. As a clinical disease, rabies is complex and nearly always fatal once symptoms appear (Hemachudha *et al.*, 2002). The incubation period in humans, which ranges from a few days to over a year, is highly variable and depends largely on site of bite, type and severity of wound, with shorter incubation period for bites inflicted in the head and other areas which are highly innervated and more severe or multiple wounds where viral concentration is likely to be higher (Rupprecht *et al.*, 2002; Warrell & Warrell, 2004). In humans the disease itself is unpredictable with non-specific onset and no definitive clinical signs beyond acute behavioural alterations and parasthesia (Hemachudha *et al.*, 2002). The characteristic clinical signs of rabies are associated with the classical "furious" rabies, which occurs in 80% of those infected (Warrell & Warrell, 1995). The symptoms of rabies in human occur in three stages. The first stage, the pro-dromal phase lasts approximately 2-10 days and is characterized by fever, nausea, headache, fatigue, and anorexia. The second phase, the sensory excitation phase or acute neurological period, lasts about 2-7 days and is characterized by behavioural changes which include extreme aggressiveness, insomnia, sensitivity to auditory and visual stimuli, hypersalivation, muscle fasciculation, convulsions, hydrophobia, and the tendency to bite and chew. The third and final phase is the coma and paralysis phase, which lasts from one hour up to a few days (Hemachudha *et al.*, 2002; Warrell & Warrell, 1995). During this period the victim has a low mental status, may suddenly be subject to cardiac or respiratory

arrest, and may become paralyzed especially in regions of the body where the virus was transmitted. The individual may enter a coma and will die shortly afterwards (Hemachudha *et al.*, 2002). The comparatively unusual presentation of rabies and resemblance of symptoms in the early stages with other neurological diseases are likely to complicate the differential diagnosis of the disease by distracting attention to other disease conditions with similar symptoms (Hemachudha *et al.*, 2002). The impact of rabies misdiagnosis might be substantial and likely to contribute to rabies under-reporting which has been identified as one of the important problems in the developing world (Cleaveland *et al.*, 2002; World Health Organization, 2004, Knobel *et al.*, 2005).

Despite centuries of empirical efforts no treatment has proved effective in preventing death once symptoms appear and rabies is nearly always fatal without proper (PEP). Rare cases of partial recovery from clinical rabies have been documented with only six cases reported since 1970, including the most recent case of an American girl in 2004. However, in all cases, recovery did not restore normal functions and life (CDC, 2004 ; Hattwick *et al.*, 1972; Porras *et al.*, 1976; Alvarez *et al.*, 1994; Madhusudana *et al.*, 2002). Atypical cases of rabies have also been reported in Ethiopian domestic dogs (Fekadu, 1975; Fekadu, 1972) raising important questions on the possibility of “carrier state” of rabies virus in domestic dogs. Overall, recovery from rabies in both human and animals is considered to be an exceptionally rare event (Jackson *et al.*, 2003).

Rabies and related viruses belong to the *Lyssavirus* genus which was until recently subdivided into seven genotypes based on RNA sequencing (Bourhy *et al.*, 1993a; Bourhy *et al.*, 1993b; Bourhy *et al.*, 1999). However, the rabies genotypes are likely to increase as a result of the recent description of four genetically distinct Lyssaviruses (Arai *et al.*, 2003; Botvinkin *et al.*, 2003; Fraser, 1996). The current known rabies virus genotypes are shown in Table 1.

Table 1.1: Rabies virus genotypes

Genotype	Description	Common species infected
Genotype 1	Classical rabies virus	Dogs, foxes, racoons bats in the Americas
Genotype 2	Lagos bat virus	Fruit bats Cats Dogs
Genotype 3	Mokola virus	Shrews, domestic cats, rodents
Genotype 4	Duvenhage virus	Insectivorous bats
Genotype 5	European bat lyssavirus (EBLV-1)	Insectivorous bats
Genotype 6	European bat lyssavirus (EBLV-2)	Insectivorous bats
Genotype 7	Australian bat lyssavirus (ABLV)	Insectivorous bats
Proposed new genotype	Aravan virus (Arai <i>et al.</i> , 2003)	Insectivorous bats
Proposed new genotype	Irkut virus (Kuzmin <i>et al.</i> , 2003)	Insectivorous bats
Proposed new genotype	West Caucasian bat virus (WCBV) (Kuzmin, <i>et al.</i> , 2004)	Insectivorous bats
Proposed new genotype	Khujand virus (Kuzmin <i>et al.</i> , 2003)	Insectivorous bats

Currently little is known about the Rabies related viruses (RRV) host range except that bats feature prominently as an important host for the viruses. It is likely that a number of infections due to RRV go undiagnosed, because the health importance of

these Lyssaviruses is unrecognised. The range of RRV is likely to expand in future with the description of new strains, such as the new Lyssavirus genotype in Australia, Asia and Russia (Fraser *et al.*, 1996; Arai *et al.*, 2003; Botvinkin *et al.*, 2003, Kuzmin *et al.*, 2003).

1.2. Epidemiology of rabies

The virus that causes rabies is a multi host pathogen capable of causing infection and disease in a wide range of mammals including man. Although virtually every mammal is susceptible to rabies, the natural disease occurs predominantly in carnivores with members of the canid, viverrid and chiropteran species known to be the most important and efficient reservoirs of the disease (Nadin-Davis *et al.*, 2001; Niezgoda *et al.*, 2002). Throughout the world, a single animal host is usually responsible for the persistence and maintenance of the rabies virus with occasional spill-over to other animal species in a given geographical area (Cleaveland & Dye, 1995; Childs, 2002; Smith, 1996).

In different parts of Europe several epidemiological cycles of terrestrial rabies exist including rabies in the raccoon dog (*Nyctereus procyonoides*), fox (*Vulpes vulpes*), and Chiroptera species. The red fox is the most important reservoir host in Western Europe followed by the raccoon dog in central and Baltic Europe. Extensive culling of foxes was implemented in Europe as a measure to control rabies but proved ineffective (Aubert, 1992), whereas oral vaccination of foxes has been successful in controlling the disease in Europe (Lontai, 1997). Available evidence suggests that when the incidence of rabies increases in foxes, it also increases in domestic species such as cattle, sheep, cats and dogs (Carter, 1977; Steck & Wandeler, 1980) with

human exposure usually occurring through contact with infected domestic animals. Where fox rabies was controlled through vaccination or elimination of foxes, the disease disappeared from all other terrestrial species, thus demonstrating that foxes are the principal reservoir host for terrestrial rabies. This example provided a justification and rationale for targeting the control of rabies in domestic dogs in the developing world where dogs are considered to be the principal reservoir host for the disease.

In North America and Canada several distinct rabies virus strains have been identified in terrestrial mammals, such as raccoons, skunks, foxes, and coyotes with all of these animal species representing different reservoirs and having a specific virus strain circulating within their populations (Krebs *et al.*, 2004; Real *et al.*, 2005). In addition to the terrestrial reservoirs for rabies, several species of insectivorous bats also serve as reservoirs. Thus different epidemiological cycles of the disease occur, corresponding to the various reservoir species, with the geographical distribution of the viruses delimited in relation to species distribution. In the USA domestic animals are often infected as a result of spill-over from wild animals (Krebs *et al.*, 2004) with cats, dogs and bovines representing important domestic animal species affected by this disease. As in Europe, early attempts to control rabies in the USA based on reduction of host population density were unsuccessful (Smith, 1996), whereas oral vaccination of the various reservoir hosts has proved to be successful in controlling the disease in USA and Canada. However, the presence of several reservoir hosts has meant that control through oral vaccination has proved to be more difficult in the USA than Europe (Uhaa *et al.*, 1992). This experience is potentially relevant for

similar rabies control problems in areas such as South Africa where multiple hosts are responsible for maintenance of the disease.

In addition to terrestrial rabies, aerial rabies due bats is increasingly assuming notable profile in the United States of America with most of the recent cases of human rabies in the United States and Canada originating from bats. During 1980-2004, a total of 56 cases of human rabies were reported in the United States. Among the 55 cases for which rabies-virus variants were obtained, 35 (64%) were associated with insectivorous bats (Krebs *et al.*, 2004). While patients with infection from sources such as dogs, raccoons or skunks usually provide a clear bite history, patients with bat-acquired rabies frequently do not report a recognized exposure (Krebs *et al.*, 2005). Failure to identify a clear risk of exposure with a bat bite or scratch is likely to be associated with the increase in bat related deaths in the United States.

In Latin America, rabies is endemic and occurs in two epidemiological cycles, terrestrial and aerial; the terrestrial cycle is maintained by domestic dogs while vampire bats (*Desmodus rotundus*) maintain the aerial cycle (Belotto *et al.*, 2005; Schneider *et al.*, 2005). Although vampire bat transmitted human rabies has lately been reported to be on the increase in the region (Schneider *et al.*, 2001; McColl *et al.*, 2000; Warner *et al.*, 1999), vampire bats are more frequently a source of infection to cattle than humans, whereas domestic dogs are the major source of human rabies (Belotto *et al.*, 2005; Acha & Malaga-Alba, 1985). The major impact of vampire bats rabies in the region has been on the livestock industry where they have

been responsible for substantial economic losses in cattle (Rellano-Sota, C, 1988; Acha & Malaga-Alba, 1985). Rabies control measures for humans in Latin America are targeted largely against the terrestrial reservoirs of the disease. Mass vaccination of domestic dogs has been very effective in reducing the incidence of both human and animal rabies in Latin America (Belotto, 2001; Schneider *et al.*, 2005; Belotto *et al.*, 2005). Various control strategies for vampire bat transmitted rabies have been recommended in the region including physical reduction or elimination of some vampire bat species, application of anticoagulants and reducing the risk of nocturnal human exposure through the use of bed nets and traps (Brass, 1994; Flores *et al.*, 1979; Flores-Ibarra & Estrella- Valenzuela, 2004; Linhart *et al.*, 1972; Rellano-Sota, C,1988b; Belotto *et al.*, 2005)

In Africa, the domestic dog is the principal source population and considered the major reservoir of rabies (World Health Organization, 1989; Fu, 1997). However, sporadic cases of wildlife rabies have been documented in the region and independent wildlife cycles of rabies have been demonstrated in jackals and yellow mongoose in Southern Africa possibly filling the same ecological niche as wildlife in other countries of America and Europe (Swanepoel *et al.*, 1993; King *et al.*, 1993; Chaparro & Esterhuysen, 1993). In the Serengeti Ecosystem, encompassing the Serengeti National Park and its environments, which is inhabited by both domestic and wild carnivores, domestic dogs have been implicated as the likely principal reservoir host for the rabies virus (Cleaveland & Dye, 1995). Questions however still remain about the role played by wild carnivores as reservoirs for the disease,

particularly in light of recent evidence which seems to suggest existence of short chains of rabies infection in wild carnivores (Lembo, 2006 under review).

1.2.2. Rabies Transmission

Transmission of rabies virus normally occurs when the infected saliva of a host is passed to an uninfected animal or human. Various routes of transmission have been documented. The most common mode of rabies viral transmission is through the bite and virus-containing saliva of an infected host, although other uncommon modes of transmission including oral, nasal, aerosol and organ transplants have been reported (Constantine, 1966; Winkler *et al.*, 1972; Winkler *et al.*, 1973; Correa-Giron *et al.*, 1970; Baer *et al.*, 1971; Bell & Moore, 1971; Ramsden & Johnston, 1975). In Namibia for instance a large number of Kudu died in 1982 in an epidemic which is thought to have spread through transmission by the oral route highlighting the potential occurrence of other considerably rare routes of rabies transmission (Bernard *et al.*, 1982). Human deaths from rabies as a result of organ transplant, such as corneas or livers from rabies infected donors have also been documented (Srinivasan *et al.*, 2005).

1.2.3. Canine rabies control

One of the key goals of infectious disease control is to bring the number of susceptible individuals from above epidemic threshold value to below threshold value, thereby preventing the threat of large scale epidemics. This can be achieved through interventions that either directly impact on the infectiousness of the pathogen

such as chemoprophylaxis, modify patterns of interaction so that the pathogen cannot easily spread through a population by for instance quarantine and isolation or immunize segments of a population . One of the fundamental epidemiological parameters upon which disease control is based is the basic reproductive ratio (R_0) (Anderson & May 1991). For micro parasites, such as rabies, this parameter is defined as average number of secondary cases caused by an infectious individual in a totally susceptible population (Anderson & May 1991). When R_0 is greater than 1, the disease can enter a totally susceptible population and the number of cases will increase, whereas when R_0 is less than 1, the disease will always fail to spread. Therefore, in its simplest form R_0 tells us whether a disease will spread through a population. The parameter is also related to the proportion of the population that must be vaccinated for infectious disease control and elimination. The objective of disease control measures such as vaccination is therefore centred on reducing R_0 to below 1, which will lead to disease elimination in a population (Anderson & May, 1992).

An infection is considered to be endemic when it can be sustained in a population without the need for external introduction. This means that every infected individual is infecting on average one other individual in the population. In mathematical terms this can be expressed as:

$$\text{Equation 1.1: } R_0 \times S = 1$$

Where R_0 is the basic reproductive number of a wholly susceptible population and S is the proportion of the population that is actually susceptible. To prevent major

epidemics and control endemic infections the proportion of immune individuals in a population needs to be sufficiently lower to keep R_0 less than 1. The minimum proportion of the population that is required to be vaccinated p_c can be derived from equation 1.1 as follows:

The proportion of susceptible and vaccinated (immune) individuals must be equal to 1. Therefore:

$$\text{Equation 1.2: } S = (1 - p_c)$$

Substituting S in equation 1.1 therefore:

$$\text{Equation 1.3: } R_0 \times (1 - p_c) = 1$$

and

$$\text{Equation 1.4: } 1 - p_c = \frac{1}{R_0}$$

and the critical proportion to be vaccinated p_c is therefore:

$$\text{Equation 1.5: } p_c = 1 - \frac{1}{R_0}$$

Rabies is a disease for which measures are currently available for its prevention and control in animals and human. The disease can be eliminated in animals through vaccination of principal reservoir host and in human through appropriately applied PEP or a combination of these approaches (Bogel & Meslin, 1990; World Health Organization, 2004). Since the production of the world's first rabies vaccine in 1885 by Louis Pasteur, significant advances have been made in reducing the burden of rabies in the world. Past and present rabies animal control strategies are based on four major approaches i) dog movement control such as tie up orders ii) culling of principal reservoir host iii) oral and parenteral vaccination of principal reservoir host

and iv) dog population control measure such as the Animal Birth Control programmes (ABC).

Successful canine rabies control or even elimination programmes have been carried out since as early as the latter half of the 19th century. In 1831 a bill was drafted in the United Kingdom ‘to prevent the spreading of canine madness’ (Meldrum, 1988) and enforcement of this legislation, which included the muzzling of dogs, restriction of their movement, and the destruction of strays and rabid dogs, along with a strict import control policy, led to the elimination of terrestrial rabies from that country in 1902. However, the disease re-appeared in the UK in 1918 and is believed to have been re-introduced by First World War servicemen returning to the country who managed to evade quarantine regulations with their rabies infected pets. The disease was brought under control again in 1922 (Muir & Roome, 2005). These measures – movement and contact restrictions, notification and observation of cases, tracing of contacts, and the killing of rabid, suspect-rabid and free-roaming dogs not in compliance with legislation – constitute the so-called ‘classical’ methods of canine rabies control.

An additional and powerful control tool became available in the 1920s, with the advent of the first effective veterinary vaccines against rabies. Japan, in 1921, was the first country to apply mass vaccination of dogs, although it was not until 1957 that rabies was eventually eliminated on this island (World Health Organization, 1966). The first field trials to demonstrate that canine rabies could be eliminated through a combination of mass vaccination and classical control measures were in

fact carried out in Hungary in 1937. This country went on to conduct the first successful national rabies control campaign, from 1939 to 1944 which resulted in successful control of rabies, making Hungary the first country on continental Europe to control the disease (Manninger, 1968). In the 1950s, several other countries followed this example, with canine rabies being eliminated from Hong Kong in 1956 and Taiwan and Portugal in 1961 (World Health Organization, 1966). Early success in Malaysia, where the disease was quickly brought under control following the initiation in 1952 of compulsory vaccination of dogs and destruction of strays (Wells, 1954), indicate that it is not only in the more developed countries that dog rabies control is possible. Since this time Malaysia has reported only sporadic cases of the disease (Tan, 1988). In Africa, both Zimbabwe (Shone, 1962) and Uganda (Arvo & Kaumba, 1971) reported dramatic declines in canine rabies cases over the ten years prior to 1961.

The control of wildlife rabies has, however, proved more difficult and challenging. Different approaches were used to control wildlife rabies in Europe. Early attempts were largely aimed at disrupting the reservoir of infection by reducing the fox density below a certain threshold. The rationale for the strategy of host population culling was primarily based on the epidemiological understanding of rabies as a density dependent disease. Indeed, reducing the population density of host animal population is one of the most frequently attempted strategies for controlling diseases in wild animals (Wobeser, 1994). The strategy has not only been applied for rabies control in foxes, but also most recently for tuberculosis control in the British badger

populations (Donnelly *et al.*, 2003). The host population culling approach derives primarily from the paradigm of threshold density for disease establishment and persistence, whose major tenet is based on the assumption that disease transmission scales positively with host population density and therefore making the population dynamics of the reservoir host critical for the epidemiological pattern of diseases in a population (Anderson & May 1991). A critical threshold density has been suggested as necessary for rabies to persist in fox populations. Below this threshold contacts appear too few for transmission to occur. For domestic dogs different studies have reported different critical threshold densities. In urban areas of the city of Guayaquil-Ecuador for instance, rabies has been reported to persist where dog population densities exceed 600 dogs/km² but occurred only sporadically in areas with lower dog population densities (Beran and Frith, 1988). In rural areas of Tanzania, Cleaveland and Dye (1995) provided evidence that rabies was more likely to be maintained in a dog population with a dog density exceeding 5 dogs/km² but not where densities were less than 1 dog/km². In Kenya a dog population density of 4.5 dogs/km² has been suggested as critical for rabies persistence (Kitala *et al.*, 2002). Due to differences in dog ownership patterns across settings dog densities and therefore critical threshold densities for rabies persistence are likely to differ widely as reported above. However, it must be borne in mind that dog densities alone cannot explain the difference reported in the studies cited above. Spatial, temporal and genetic heterogeneities that affect contact rate and infection transmission are also likely to play an important role. Although the critical threshold phenomenon has been well studied in the context of wildlife rabies, it has not been widely and adequately quantified for domestic dog populations.

Fox culling programmes in Europe did not achieve the anticipated results. Fox populations retain a high potential to recover from natural and anthropogenic perturbations. When foxes are removed from a population, as previously occurred with fox culling, compensation occurs resulting in a lower natural mortality or emigration, or birth rates increase thus enabling the population to grow faster than it did before the cull. Culling is also likely to result in social instability in fox populations causing an increased dispersal of the fox population and consequently an increased spread of rabies over wider adjacent areas that could have been rabies free prior to the culling programme (Aubert, 1994; Macdonald & Bacon, 1982; Blancou *et al.*, 1991). The experience gained from previous fox culling projects and the “perturbation effect” in the UK badger populations in an attempt to control bovine tuberculosis provides an important lesson on the impact of anthropogenic interventions on wildlife and disease control. Badger culling for example is believed to have resulted in a disruption of the badgers’ population territorial and social system thus causing an increased dispersal which is believed to have resulted in increased opportunities for intra-specific disease spread over wider areas thereby increasing the opportunity for disease persistence in the badger population (Macdonald *et al.*, 2006).

At the beginning of 1960s the possibility for oral vaccination of foxes against rabies was suggested as an alternative to culling, but it was not until 1970 that strong scientific evidence for the effectiveness of oral vaccines for foxes was available. The

first successful campaign was conducted in Switzerland in 1978 resulting in the elimination of rabies in a large part of the country within four years (Steck *et al.*, 1982b; Steck *et al.*, 1982a; Kappeler & Wandeler, 2000). Fox rabies has since been controlled in other West European countries, such as France and Belgium and significantly reduced in Central and Eastern European countries following major political changes in this European region (Aubert *et al.*, 1994; Stohr & Meslin, 1996). The control of fox rabies in Europe through oral vaccination provides a very important historic example of pathogen elimination from wild animal population by means of vaccination and not by means of reduction of a host population.

Rabies control strategies in the developing world are, to a large extent, reminiscent of the rabies control model in the developed world. The UK canine rabies control model, which included dog movement restriction, destruction of strays and rabid dogs and leash orders, still forms a part of the rabies control policies in many developing world countries. Dog culling, which is based on the same principal as the failed fox culling strategy in Europe, is still widely practiced in the developing countries despite the existence of ample evidence and knowledge about its ineffectiveness in controlling both dog populations and rabies (World Health Organization, 2004; Bogel & Meslin, 1990). Studies on dog ecology and population dynamics in developing countries, conducted under the auspice of the World Health Organization in Sri Lanka, Ecuador and Tunisia (World Health Organization, 1988), have demonstrated that in order to attain a lasting reduction in dog population size, dog culling programmes would need to remove 50-80% of the population each year.

However in Sri Lanka, where sustained dog elimination campaigns had been conducted since 1977 despite removing between 35,000-50,000 dogs annually, these programmes were only successful in reaching 5% or less of the targeted dog population. A concerted effort in Guayaquil, Ecuador, which resulted in the removal of 24% of the dog population over a period of 12 months, was reported to have no lasting impact on the size of the dog population, nor on the incidence of canine rabies (World Health Organization, 1988). In fact, the community response to dog elimination campaigns in Guayaquil and elsewhere was to purchase new puppies or to adopt free-roaming dogs that move into the area to fill the vacant niche. Due to the fact that these dogs are likely to be unvaccinated, and because the elimination campaigns themselves often remove vaccinated dogs (4% of killed dogs in the Sri Lankan study were found to have demonstrable serum rabies virus neutralizing antibody titres), dog elimination campaigns are also likely to indiscriminately reduce the proportion of immunized individuals in a population, and thus decrease the level of ‘herd immunity’.

Overall, the WHO report (1988) concluded that not only did dog elimination programmes not have any significant long-term effect on dog population size but they also incited animosity towards rabies control personnel in local communities thus resulting in decreased cooperation during mass vaccination campaigns. This viewpoint is further supported by results of recent similar campaigns undertaken to control dog rabies in Flores, an island in Indonesia that had previously been rabies-free, and in which 295,565 dogs were killed over a four year period as a means to

stop an expanding rabies epidemic. Dog culling in Flores was not successful in preventing further spread of rabies amongst both dogs and humans (Windyaningsih *et al.*, 2004), in large part due to the unpopularity of the culling scheme, as most dogs on this island were owned (Bingham, 2001). By May 2004, 48% of the island's dog population had been destroyed, but rabies transmission continued. This highlights the fact that even large scale culling of the dog population, without an intensive vaccination campaign, is unlikely to be effective as a rabies control strategy.

Despite major advances in vaccination technology, rabies is still uncontrolled in many parts of the developing world, including some parts of Europe, largely as a result of financial limitations and poor infrastructure. In Africa, rabies incidence has been reported to be increasing in several countries (Perry, 1993; Cleaveland, 1998). The control of canine rabies therefore remains a major challenge for Veterinary Services in most developing countries.

In many countries of the developing world where the dog is considered to be the principal reservoir of the rabies virus, few rabies control programmes are being implemented despite the fact that canine and human rabies incidence is high and even increasing (Perry, 1993). Even the few national rabies programmes which are being implemented in canine rabies endemic countries have been comparatively ineffective in controlling the disease (World Health Organization, 2002). In Latin America, where a clear plan of action for elimination of rabies is being implemented, substantial progress has been made in controlling canine rabies. Countries in the region have concentrated rabies control efforts on vaccination of domestic dogs, PEP

and epidemiological surveillance. As a result the incidence of both animal and human rabies has decreased by up to 82% and 81% respectively (Belotto *et al.*, 2005). The success achieved in this region is attributed to the motivation and clear commitment of the Pan American Health Association and national governments which provide the continued political, logistic and budgetary support required for implementation of rabies control measures in the region. In addition technical cooperation between governments and inter-sectoral collaboration has been established and is one of the key elements behind the successes in the region (Belotto *et al.*, 2005; Schneider *et al.*, 2005). All of these factors clearly distinguish the successful Latin American rabies control strategies from the failed African rabies control programmes and highlight the need for a paradigm shift in the rabies control programmes in African countries.

1.2.4. Rabies surveillance

Vaccination of the animal reservoirs is not the sole requirement for a successful and effective rabies control programme. Improved disease surveillance and public education are essential elements to raise community awareness about rabies prevention and control programmes in developed countries. However, these aspects have not been adequately addressed in developing countries. In the developing world, including Tanzania, surveillance systems, particularly for diseases such as rabies which do not command high priority among policy makers, are known to be inadequate (Kitala *et al.*, 2000; World Health Organization, 1992).

The smallpox elimination programme has provided an important lesson on the importance of surveillance in disease control/elimination programmes. During the global smallpox eradication programme, the continued occurrence of cases despite high vaccination coverage, led to development of a new strategy for eradication based on the identification and vaccination of a wide circle of potential contacts around each reported case. This created a “wall of immunity” around all cases and led ultimately to the global elimination of smallpox (Foege *et al.*, 1971). In the case of small pox an effective surveillance system led to the understanding that a new strategy involving increased surveillance was required to achieve disease eradication.

The primary purpose of surveillance in a rabies control programme, is to assist veterinary and public health officials in overall programme planning and to provide guidance in evaluating the need to administer PEP to patients who have been exposed to potentially rabid animals. In Tanzania, rabies surveillance programmes have traditionally relied on a passive surveillance approach with reports received largely from the veterinary and medical authorities. However the rabies surveillance infrastructure and reporting systems in Tanzania and elsewhere in the developing world are generally inadequate, leading to a gross under-reporting of the disease incidence resulting in difficulties in evaluating the epidemiological, economic and public health trends of the disease (Cleaveland *et al.*, 2003; Cleaveland *et al.*, 2002; Kitala *et al.*, 2000; World Health Organization, 1984).

1.2.5. Rabies diagnosis in animals and human

An important requirement for the surveillance and control of any disease is the facility for accurate diagnosis. Rabies diagnosis is necessary for various reasons including evaluating the epidemiological patterns and overall impact of rabies control measures. In addition, rapid and accurate diagnosis of rabies in animals is essential for timely administration of PEP in humans in order to save patients from unnecessary physical and psychological trauma and financial burden in the event that the animal is not rabid.

Due to limited infrastructures, rabies diagnosis in Tanzania as well as in much of the developing world is often based on the clinical signs of the presenting patient or suspected rabid animal. Although diagnosis made on clinical grounds alone can be useful and may be relatively accurate (Cleaveland *et al.*, 2003) a definitive diagnosis of rabies requires reliable laboratory testing (WHO 2004). Evaluating the presence of rabies based on clinical diagnosis alone will undoubtedly lead to an over or under-reporting of the disease. In domestic dogs for instance signs of other diseases such as distemper, hepatitis, listeriosis, tetanus, botulism and some parasitic diseases may be similar to those of rabies. In human rabies may resemble numerous other encephalitic syndromes such as the Guillain-Barre like syndrome (World Health Organization, 1992). The Guillain-Barre like syndrome is a rare human disorder in which the body's immune system attacks part of the peripheral nervous system. The first symptoms of this disorder include varying degrees of weakness or tingling sensations in the legs spreading thereafter to upper parts of the body (Douglas & Winer, 2006).

These symptoms can increase in intensity until the patient is almost totally paralyzed.

These symptoms are likely to be confused with the paralytic form of rabies.

A reliable and sensitive diagnostic test is essential for use in epidemiological studies and disease control. In addition, because rabies has a 100% case fatality rate, laboratory diagnostic tests need to be rapid and economical. The WHO recommended routine laboratory techniques, which form the basis of rabies surveillance, are published in details elsewhere (World Health Organization, 2004; Dean, 1996). The direct fluorescent antibody test (DFAT) is the gold standard for rabies diagnosis and is the most frequently used and recommended test for post-mortem diagnosis of rabies (World Health Organization, 2004). This assay is however, relatively expensive, cumbersome and requires a certain level of expertise (World Health Organization, 2004). In addition it requires the use of a specialized and sophisticated fluorescent microscope as well as rabies testing biologicals which can be difficult to maintain under field conditions. More rapid and less expensive immuno-histochemical tests that can potentially be used under field conditions, with relatively little expertise, have recently been described (Madhusudana *et al.*, 2004; Lembo *et al.*, 2006).

1.2.6. Public health and economic impacts of canine rabies control

Despite marked and rapid development in technology and knowledge about rabies prevention and control and the widespread availability of effective, cheap and safe

canine and human vaccines, rabies remains an important global public health problem, a significant threat to wildlife conservation and a health economics concern (Meltzer & Rupprecht, 1998b; Meltzer & Rupprecht, 1998a; Bogel & Meslin, 1990; Fishbein *et al.*, 1991, Knobel *et al.*, 2005; Gascoyne *et al.*, 1993; Gayscoyne *et al.*, 1995). As a public health problem, rabies provides a clear and typical example of where poverty perpetuates human suffering, despite the availability of control tools and strategies. Today, PEP with modern inactivated cell culture vaccines and rabies immunoglobulins is universally effective in preventing human death due to rabies (World Health Organization, 2004). As a result, human deaths from rabies are now exceedingly rare in the developed world. In the USA and UK for example, only one to two human rabies death occur each year, a reduction of more than 100 per year at the start of 20th century (Bourhy *et al.*, 2005; Belotto *et al.*, 2005). In contrast, in the developing world where more than 2.4 billion people live in areas where dog rabies is endemic, the control of rabies continues to pose a great challenge. The disease remains uncontrolled in large part of the developing world with incidence increasing annually (Cleaveland, 1998; Perry, 1993). The developing world accounts for over 99% of all worldwide human deaths due to rabies (Acha & Arambulo, 1983). Although surveillance and reporting are poor, a recent study has estimated that human deaths due to rabies in Asia and Africa alone amount to over 55,000 people per year with 1.8 million disability adjusted life years (DALY a composite measure of human disease burden) lost annually (Knobel *et al.*, 2005). The World Health Organization estimates that 10,000,000 humans receive PEP annually (World Health Organization, 2004) with children under the age of 15 years being the population most frequently affected.

Evaluation of the public health and economic burden of infectious diseases is customarily based on human morbidity and mortality and recently on DALYs. For most infectious diseases of humans, these measures are likely to adequately reflect the economic impact. However, for multi host pathogens like rabies, which are by definition capable of infecting several host species including humans, the evaluation of the economic impact must go beyond human mortality, morbidity and DALYs, and must include the economic impact of the disease on livestock loss and wildlife conservation.

There are, however, only a few country-level estimates on the macro-economic impact of rabies. The available estimates suggest that rabies impinges greatly on national economies and control of the disease should result in significant savings in national health budgets. In the Philippines, for example, it is estimated that control of rabies would result in a net economic benefit of up to \$2.5 million annually (Fishbein *et al.*, 1991).

The economic benefits of ensuring the survival of endangered wildlife populations such as wild dogs and Ethiopian wolves through dog rabies control remain to be quantified, with the quantification of the economic benefits from wildlife presenting a challenging problem. However, wild dogs are reported to be one of the major attractions for tourists visiting South Africa National Parks (Lindsey *et al.* 2005) and, given the importance of wildlife tourism in the economies of many countries in sub-Saharan Africa, these economic effects should not be ignored.

Rabies also affects the economy of individual household. A large proportion of the rural population in Africa and Asia subsists below the poverty line and yet it is in these rural areas that rabies has its most profound economic impact. Knobel *et al.* (2005) predict that five times more rabies deaths occur in rural as opposed to urban areas. The greatest problem at the household level is likely to be the expense associated with PEP. The human rabies vaccine is not only expensive relative to rural household incomes but is also rarely available in the vicinity of most rural populations who, more often than not, are thus compelled to travel long distances to obtain PEP therefore paying for both travel and boarding costs. In addition, dog bite victims are likely to be unable to meet the relatively expensive costs of PEP. In India for example a labourer was compelled to sell one third of his land to raise the required funds to pay for his child's PEP although the child eventually died (Dutta, 1996). The experience from India is likely to be applicable in most of the developing world countries.

Rabies has also been documented to cause substantial livestock losses, particularly in pastoral or agro-pastoral areas. Using household questionnaire survey to estimate the livestock economic loss due to rabies it was reported that livestock rabies mortality in Ethiopia causes an economic loss of up to \$7.5 per year (Laurenson *et al.*, 1997a), a considerable impact in a country where many households earn less than \$1 a day. Although studies on livestock losses due to rabies are few, anecdotal evidence from some parts in north western Tanzania suggests that the problem is likely to be greater than originally surmised.

1.2.7. Rabies in Tanzania

Rabies was reported for the first time in Tanzania in Dar es Salaam in a dog belonging to the Provincial Commissioner in 1923 (Ministry of Livestock Development, 2006) and the disease has been endemic ever since (Magembe, 1983). As in most of the developing world, the domestic dog is the most important source of rabies for humans in Tanzania. Cases of humans bitten by suspected rabid wild animals are relatively sporadic and are largely confined to areas bordering wildlife protected areas, although the role of wildlife as reservoirs is reported to be unlikely (Cleaveland & Dye, 1995). However, further investigation regarding the possibility of a wildlife reservoir is currently under review (Lembo, 2006 under review). An annual average of 2418 animal rabies cases, diagnosed on clinical grounds only, was reported to the Tanzania Ministry of Water and Livestock Development between 2001 and 2005 (Fig 1.1). Numbers of human rabies cases reported to the Ministry of Health are reported in Figure 1.2 reflecting large fluctuation in the number of human cases reported which is likely to be attributed to human bites reporting problems at lower levels (district and regional hospitals).

The disease, as in most of the developing world, is highly under-reported in both human and animals. A recent study in Tanzania which used community based active surveillance measures, whereby village based livestock field officers stationed in villages followed up and collected data on cases of suspected rabid dogs and humans bitten by suspected rabid dogs and hospital passive surveillance data collected from district hospitals in the region, estimated up to 100 times under reporting of human rabies mortality in the country (Cleaveland *et al.*, 2002).

Figure 1. 1: Animal rabies cases reported to the Epidemiology unit of the Ministry of Water and Livestock development in Tanzania from 2001 to 2005 based on clinical diagnosis

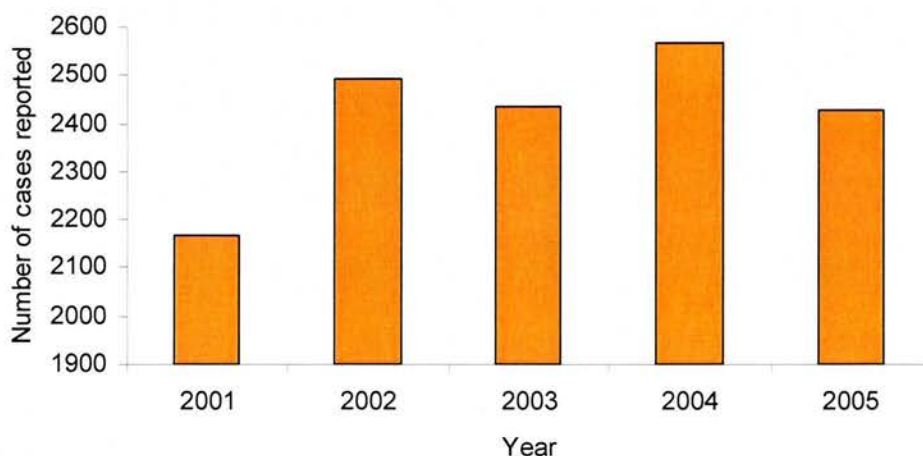
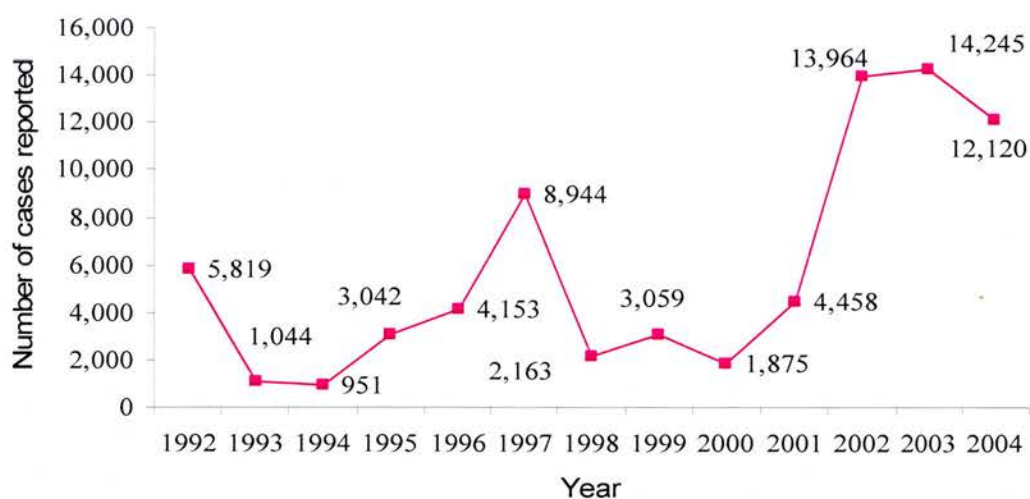


Figure 1. 2: Human rabies cases reported to the Ministry of Health from 1992 to 2004 based on clinical diagnosis of cases at district hospitals



There has been no clear rabies control strategy in Tanzania despite a reported increase in incidence over the last ten years. The Government of Tanzania imported 60,000 doses of dog rabies vaccine in financial year 2003/04 and 50,000 doses in 2004/05 which were subsequently distributed to 30 districts reporting rabies

incidence throughout the country (Ministry of Water and Livestock Development, 2004). Although private veterinary practitioners are likely to import rabies vaccine, information obtained from the Food and Drug authority, the regulatory body for importation of biologicals indicate that not more than 75,000 doses of rabies vaccine in total were imported by private practitioners for five years from 2000 (Luwongo pers.com). With an estimated dog population of some 4,000,000 dogs, the amount of rabies vaccine appears to be far below the requirements to adequately control canine rabies in the country. The Ministry of Health distributed 16,200 doses of human anti-rabies vaccine in the country in 2004 (Ministry of Health, 2004). The vaccine was distributed on a “demand driven” policy with district that reported more cases of humans bitten by suspected rabid dogs getting more vaccine. Prescription to dog bite victims was based on clinical diagnosis with patients required to contribute toward the vaccine cost.

1.2.8. Design of rabies vaccination programmes

Vaccination programmes against infectious diseases are one of the most effective public health interventions, but the success of these programmes depends on achieving and maintaining critical vaccination coverage rates. The WHO recommends the threshold vaccination coverage of 70% to effectively control rabies in dog populations (World Health Organization, 2002) and these data are supported by theoretical studies (Coleman & Dye (1996). However canine vaccination coverage levels achieved in most mass vaccination programmes in the developing world fall far short of the recommended threshold level. Perry (1995a), for instance,

estimated vaccination coverage levels ranging from 2.4% to 12.9% in Kenya, Malawi and Tanzania which are grossly below the 70% threshold.

To date, few successful dog rabies vaccination programmes have been reported. Cleaveland *et al* (2003), for example, reported an effective rabies vaccination programme in rural Tanzania with a vaccination coverage rate of 65% which subsequently reduced the incidence of human bites from suspected rabid dogs by 92%. In Zimbabwe, Brooks (1990) reported that vaccination coverage rate of 50% was sufficient to control rabies in domestic dogs. In Chad Kayali *et al* (2003) achieved a coverage range of 67-87% although they did not demonstrate the effectiveness of this coverage level in relation to canine and human rabies incidence. In a vaccination trial in sub-urban area in Kenya, Perry *et al* (1995b) were able to achieve a coverage rate of 68-75%, whereas in Brazil, using a synchronized rabies vaccination programme, a strategy which has not been widely adopted elsewhere in the developing world, a vaccination coverage rate of up 88.2% was achieved. This resulted in a substantial reduction in the incidence of human and canine rabies (Belotto, 1988).

One of the important lessons to be learned from these vaccination programmes is that effective vaccination coverage levels can be achieved through properly planned and implemented simple central point mass vaccination programmes. In addition, effective coverage levels are likely to differ in each area depending on many factors including those that influence potential contact rates between infected and susceptible dogs, such as dog density. However most of the successful campaigns

that have been reported are generally small scale vaccination trials and findings obtained from this trial may be difficult to extrapolate and generalize over the wider population, thus highlighting the need for large scale interventions.

The World Health Organization recognizes effective delivery of rabies vaccine as the principal challenge for rabies control in the developing world (World Health organization, 2004). Studies conducted in some parts of Africa, Asia and Latin America have reported that a substantially large proportion of domestic dogs is likely to be accessible for parenteral mass vaccination (World Health organization, 2004). For communities where domestic dogs are less likely to be accessible for parenteral vaccination, the WHO recommends oral vaccination as a supplementary strategy (World Health organization, 2004)

Despite major advances in technology and knowledge about vaccines and vaccination strategies there still remains considerable uncertainty concerning the optimal design for both medical and veterinary vaccination programmes. The design of vaccination programmes has been extensively evaluated in the context of theoretical epidemiology of childhood infections such as measles, mumps and rubella (Anderson & May, 1990). Except for the recent Foot and Mouth outbreak in UK and fox rabies in Europe and North America, theoretical epidemiology has received limited attention in the context of veterinary diseases. Woolhouse *et al.*, (1977) outlined some of the important parameters to consider in the design of vaccination programmes. These parameters include the proportion of host population that has to

be vaccinated in order to eliminate or control a disease and the inter-vaccination interval, both of which are discussed in detail by Anderson & May (1991). In addition, a number of demographic, ecological, logistic, economic, social and cultural factors are likely to influence the outcome of vaccination campaigns and thus disease control. Host population, spatial, genetic and behavioural heterogeneities have also been identified as key factors for optimal design of disease control programmes (Barbour, 1978; Dye & Hasibeder, 1986; Woolhouse *et al.*, 1991; Woolhouse *et al.*, 1997). Targeting disease control measures against “core disease transmitters” has been suggested as one of the strategies that should be considered in the design of disease control programmes (Woolhouse *et al.*, 1997).

A number of practical issues and strategic factors are likely to influence decisions on the design and implementation of mass vaccination programmes for domestic dogs. In rural Tanzania and Kenya for example, it has been demonstrated that pulse mass vaccination campaigns that will maintain sufficient herd immunity, need to be repeated every 6-8 months, rather than the one year inter vaccination interval more commonly observed (Cleaveland, 1996). Inclusion of puppies less than three months old has also been suggested in order to achieve recommended critical coverage levels and optimize cost effectiveness of mass dog rabies vaccination programme (Coleman, 1999; Cleaveland, 1996).

1.2.9. Objectives

The main objective of this study was to investigate and identify the optimal domestic dog vaccination strategy for rural Tanzania in order to reduce the incidence of rabies

in the local human population, domestic dogs, livestock and wild animals in surrounding wildlife protected areas.

Specific objectives of this study were:

- I. to evaluate social, cultural, economic, organizational and spatial factors that influence domestic dog vaccination coverage in rural Tanzania
- II. to investigate and quantify the economic burden due to rabies faced by households in a Tanzanian community
- III. to assess and estimate the impact of multivalent dog vaccination on dog population demography and incidence of animal and human rabies.
- IV. to estimate the *per capita* cost of alternative domestic dog vaccination strategies and estimate the public health benefit of canine rabies control
- V. to investigate and recommend optimal design of domestic dog mass vaccination programmes in rural Tanzania

**Chapter II: Social- cultural, economic and spatial factors influencing domestic
dog rabies vaccination coverage in rural Tanzania**

2.0. Introduction

Failure to control rabies in the developing world has led to research that has focused primarily on the influence of domestic dog ecology and demography on the accessibility of dogs for parenteral vaccination and cost effectiveness of control strategies (Coleman, 1999; Kitala *et al.*, 2001; Kitala *et al.*, 1993; Balogh *et al.*, 1993; Cleaveland, 1996; Bogel & Meslin, 1990; Fishbein *et al.*, 1991). Although in general terms rabies control efforts in the developing world have not been successful, some vaccination campaigns in the region have demonstrated that well planned and implemented vaccination campaigns are able to substantially improve vaccination coverage. Such campaigns have resulted in a significant reduction in the incidence of rabies in both dog and human populations (Cleaveland *et al.*, 2003; Perry *et al.*, 1995; Belotto, 1988; Kayali *et al.*, 2003) thus raising the prospect for the possibility of rabies control and eventual elimination in the domestic dog population in the region. However, the implementation of central point dog vaccination against rabies (whereby owners bring dogs to a centrally located static point) depends on owners' compliance to bring their dogs for vaccination. The owners' decision is therefore likely to be influenced by social, cultural and economic factors prevailing at any given time and perhaps other factors (Wandeler *et al.*, 1993; Acha & Arambulo, 1983).

In comparison with medical vaccination programmes, only a limited number of studies have attempted to investigate the influence of the social, cultural, organizational and economic factors that are likely to influence the effectiveness of

veterinary vaccination programmes. The experience of medical studies highlights several key issues. Streefland (1995) underscores the importance of local community support and the need for implementation of vaccination strategies that are tailored to the prevailing local socio-cultural realities. In their investigation on the quality of child vaccination services and social demand for vaccinations in Africa and Asia, Streefland *et al.*, (2001) noted that impolite vaccinators' behaviour, occurrence of post vaccination side effects, poverty and distance from static vaccination points were important factors that influenced vaccination coverage. In Bangladesh socio-economic and cultural disparities were identified as important factors contributing to low child vaccination coverage in disadvantaged areas (Chowdhury *et al.*, 2003).

The findings from medical vaccination programmes, to a large extent, are likely to apply to veterinary vaccination programmes including domestic dog vaccination where owner cooperation is required. Attitudes towards dogs are known to vary widely in different cultural settings and from tribe to tribe (World Health Organization, 1984; Acha & Arambulo, 1983; Wandeler *et al.*, 1993). Dog vaccination against rabies can potentially be improved or compromised because of the inherent socio-cultural attitudes towards dog keeping practices and ownership patterns. For example, it has reported that in Thailand, where dogs are worshiped and adored, religious factors related to dog ownership can be advantageously used to improve accessibility of domestic dogs for parenteral vaccination (Bogel & Joshi, 1990). Therefore in Thailand, recommendations have been made for dog vaccination to be part of, or carried out in conjunction with, local religious ceremonies. However, in some parts of developing world religious and cultural beliefs have been

demonstrated to be a major hindrance and have hampered the accessibility of dogs for central point parenteral vaccination. For example in some communities dogs are considered unclean and rejected by society (Matter & Daniels, 2000). As a result in Ethiopia, for example, parenteral dog vaccination has resulted in relatively low coverage partly because of reluctance of the predominantly Muslim community to handle dogs (Laurenson *et al.*, 1997; Knobel, pers.comm). A similar observation has been documented in the Maasai pastoral communities in North Tanzania where people are not used to handling and restraining dogs despite the community being largely non-Muslim (Cleaveland, 1996). The current knowledge of social, cultural, organizational and economic factors which are likely to influence the accessibility of domestic dogs for parenteral vaccination under different settings is inadequate. A detailed understanding of these factors is therefore important and is investigated in this Chapter.

2.1. Dog movement restriction

The classical dog ecology literature considers the dog population to be comprised of owned and ownerless dog population segments (Matter & Daniels, 2000). This has resulted in terminologies such as “pet”, “owned”, “ownerless” or “stray” to describe different categories of dog population. However contemporary research on dog ecology has provided a redefined and probably more accurate evaluation of dog population categories based on i) the level of a dog’s dependency on humans and ii) the level of its restriction by humans (Bogel & Joshi, 1990; Bogel, 2002). This new concept in dog ecology has resulted in the adoption of four new dog population categories (Bogel, 2002):

- i. Restricted dog – fully dependent of their owners and fully restricted or supervised
- ii. Family dogs – fully dependent of their owners, but movement and contacts only partially restricted
- iii. Neighbourhood dogs – partially dependent on the intentional fulfilment of basic needs by humans, but subject to only partial or no restriction
- iv. Feral dogs – independent of intentional human provisioning and unrestricted

The categories of dog population based on the level of a dog’s dependency on humans and the level of its restriction by humans is considered to be more useful in determining the relative accessibility of dog population segments for parenteral vaccination (Table 2.1)

Table 2. 1: Dog categorisation matrix and index of accessibility* to parenteral vaccination

	Fully restricted	Semi-restricted	Unrestricted
Full dependency	Restricted dog +++	Family dog ++	
Semi-dependency		Neighbourhood dog +	Unrestricted dog +/-
No dependency			Feral dog -

*Index of accessibility is an assessment of the typical ease of accessibility of dogs within each category to parenteral vaccination, ranging from very easily accessible (+++) to inaccessible (-)

Studies in Kenya and Thailand have shown that a significantly high proportion of rural dogs are rarely restricted in their activities and movement (Kongkaew *et al.*,

2004; Kitala *et al.*, 2001; Kitala *et al.*, 1993). This observation is also likely to be true for most African countries. Studies have also demonstrated that although most dogs may be unrestricted and found roaming freely over wide ranges without supervision, most of them are recognizable by the community and can be linked to specific known households and are therefore likely to be accessible for parenteral rabies vaccination (Matter & Daniels, 2000). Ecological studies of rural dog populations have demonstrated that the proportion of dogs that are independent of intentional human provisioning and restriction and thus likely to be inaccessible for parenteral rabies vaccination is probably very small comprising fewer than 20% of the dogs in Zambia and 10% of the dogs in Sri Lanka (de Balogh *et al.*, 1993; Matter *et al.*, 2000).

Unrestricted family, neighbourhood and feral dogs that have little or no supervision may cause more problems to the public than restricted dogs due to scavenging food, causing road accidents, inflicting wounds to people, frightening the public, attacking livestock and wildlife, fouling public places and transmitting diseases (Leney & Remfry, 2000). The risk of bite injuries and transmission of dangerous diseases to human such as rabies is a major concern. In terms of rabies control by mass vaccination, accessibility is likely to be lowest in feral dogs followed by free neighbourhood and family dogs.

Epidemiological theory and empirical studies indicates that rabies can be controlled if 70% of dog population is vaccinated (Coleman & Dye, 1996; World Health Organization, 1987). This is, however rarely achieved in most dog vaccination

programmes in Africa, where coverage levels as low as 4% to 20% have been reported (Perry *et al.*, 1995; Kitala *et al.*, 2002; Cleaveland, 1998). Failure to achieve the recommended coverage has been partly attributed to a high proportion of inaccessible unrestricted dogs. This factor has led to implementation of dog population control measures through killing by shooting or poisoning. However, these dog control measures were never effective in controlling either dog population or rabies and are now considered untenable in view of the contemporary understanding of rabies epidemiology and ecology of dog population (World Health Organization, 1988; Bogel & Joshi, 1990; Bogel, 2002). Knowledge of the proportion of the various categories of dog population and their likelihood of being accessible for parenteral vaccination is therefore important for the design of appropriate rabies control strategies and is investigated in this Chapter.

2.1.2. Dog function

Although in most developing countries domestic dogs are largely kept for security reasons (Matter & Daniels, 2000) dogs may also be kept for additional reasons such as religious purposes, medicinal purposes, consumption, herding and hunting (Matter & Daniels, 2000). Understanding the reason why people keep dogs may provide an indication of the extent to which dogs may be accessible for parenteral vaccination. For example dogs which are kept as companion are likely to be present at home more often than hunting and cattle herding dogs. Companion dogs are therefore likely to be more accessible for vaccination than dogs used for hunting and herding livestock.

2.1.3. Source of dogs

Understanding the source from which owners obtain dogs is important in giving an indication of spatial dog mobility. Immigration of dogs through high mobility rates between different dog populations is likely to have an important impact on dog population turn over rates. One of the potential reasons for dog immigration is the acquisition of new dogs by people. High rates of acquisition of new susceptible unvaccinated dogs by owners in a vaccinated population may result into significant decline in vaccination coverage. Quantifying the degree of dog acquisition from one village to the other may therefore provide an indication of how likely vaccination coverage will remain stable over time. Studies have identified four major sources of dogs for rural owners. These include puppies whelped by bitches from within the household, receiving dogs without payment from other household, adopting abandoned dogs and purchasing dogs from other households (Matter & Daniels, 2000; Cleaveland, 1996).

2.1.4. Vaccination coverage and distance from central vaccination point

The relationship between vaccination coverage and distance from the central vaccination point remains to be fully investigated. Nevertheless, vaccination trials in the remote and dispersed pastoral Maasai community in Kenya have demonstrated that vaccination coverage decreased by 95.3% with every 1 km increase in distance from the central vaccination point (Coleman, 1999). In Tanzania, Cleaveland (1996)

observed that dogs were more likely to be accessible within a catchment area of 1 km from the central vaccination point. These studies highlight the need for consideration of critical catchment area when setting up central vaccination points, but due to their small scale, or limited geographical scope, there is need for larger and geographically diverse investigation for more rigorous analysis.

2.1.5. Age at which to vaccinate

Rabies vaccine manufacturers generally recommend that pups from immunized bitches should be at least three months of age at vaccination to avoid interference from maternally-derived antibodies (MDAs) with the development of immunity. This has therefore been adopted as policy in most of developing countries (Beran & Frith, 1988). Some laboratory trials support this premise and have demonstrated failure of inactivated rabies vaccine to elicit antibody response in puppies with MDAs (Prècausta *et al.*, 1985). However, trials involving infection challenge have indicated that the presence of MDAs in puppies is unlikely to have any significant interference on actively induced vaccine immunity in puppies as young as two weeks old (Chappuis, 1998). Field vaccination trials in Tunisia have demonstrated that puppies (dogs less than three months old) are capable of responding to rabies vaccination without any significant interference by MDAs (Seghaier *et al.*, 1999). Perry *et al.*, (1995) highlighted the importance of including pups in rural Africa rabies vaccination campaigns and noted that excluding dogs less than three months old in rabies vaccination campaigns is likely to result into failure to maintain the required temporal herd immunity for rabies control. Theoretical studies have reported that inclusion of

pups in rabies vaccination campaigns is likely to result in substantial epidemiological and economic benefits (Coleman, 1999; Cleaveland, 1996).

The aim of this study was to evaluate social, cultural, organizational and spatial factors that are likely to influence the accessibility of domestic dogs for central point parenteral vaccination through assessing the influence of village, household and dog characteristics on vaccination coverage. Village characteristics evaluated included the influence of village proximity to district headquarters, nearest district hospital locations where PEP is ideally supposed to be available and the degree of publicity prior to the vaccination campaign. Household characteristics included ethnicity, socio-economic status, and number of dogs in a household, livestock ownership, household knowledge prior to a rabies vaccination campaign and household distance from a central vaccination point. Dog characteristics evaluated in this study included age and sex of dog and degree of dog movement restriction. The study focused on two distinct social-cultural settings in north western Tanzania, particularly the Kurya and Sukuma, the two major ethnic communities located around Lake Victoria.

2.2. Materials and methods

2.2.2. Study area

The study was part of a large scale research project in north-western Tanzania which has implemented mass dog vaccination as an intervention to investigate the infection dynamics of three carnivore viral diseases namely rabies, canine distemper virus (CDV) and canine parvovirus (CPV) in multi-host communities of the Serengeti. The present study exploits the opportunity provided by the vaccination campaigns to describe social, cultural, economic and dog population characteristics that are related to vaccination coverage.

The study area involved 6 districts of Bariadi, Bunda, Magu, Meatu, Serengeti and Tarime situated in north-western Tanzania in the regions of Mara, Mwanza and Shinyanga and was divided into two zones based on their location relative to Serengeti National Park. The study zone is detailed in Figures 2.1 and 2.2. The vaccination zone comprised all villages in the six districts situated within 10 km distance from the border of the Serengeti National Park or surrounding game reserves. Vaccination against rabies was implemented in this zone using a multivalent rabies vaccine which also provided protection against CDV, canine hepatitis virus (CHV) and CPV. The vaccination programme was implemented in three separate campaigns in 2003, 2004 and 2005. Within the vaccination zone a total 12 villages, two in each district, were randomly selected from a list of a total of 145 villages within the zone for comparison and follow up.

Figure 2. 1: Maps of Africa and Tanzania showing the location of study area in North Western Tanzania

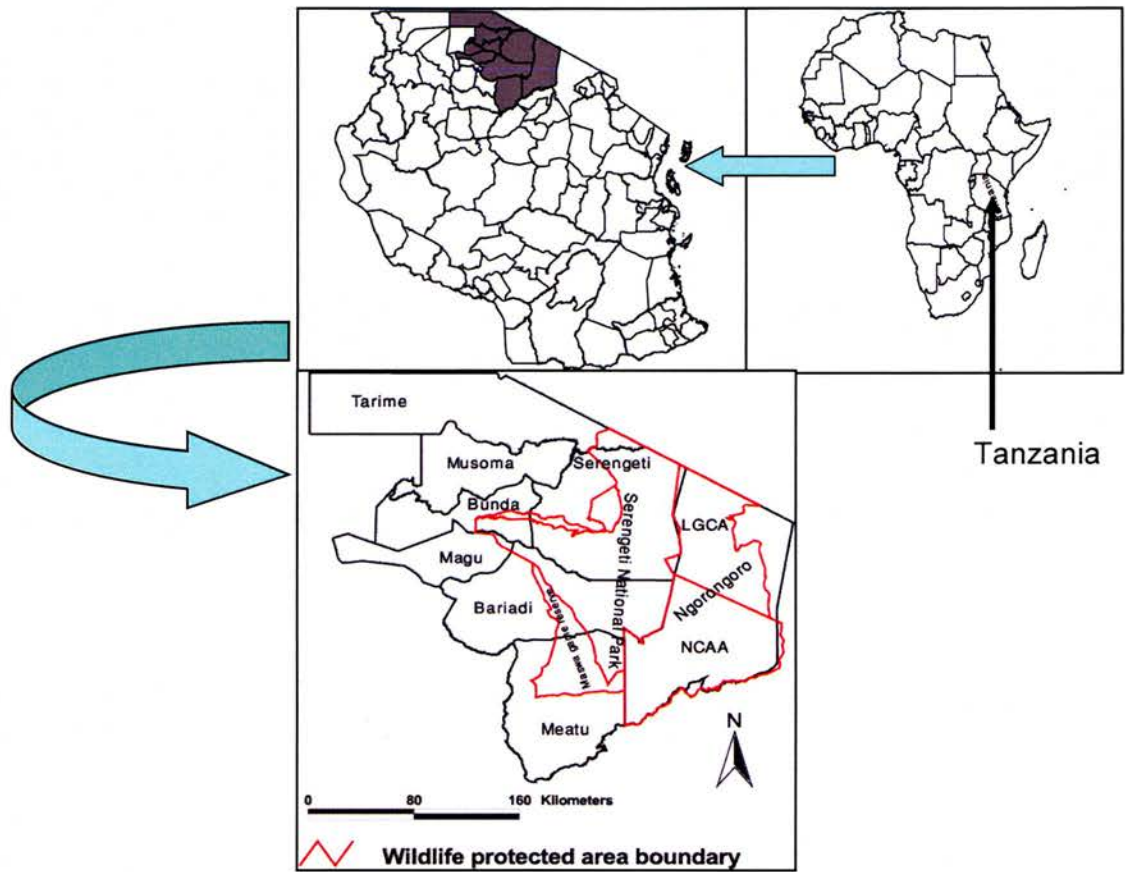
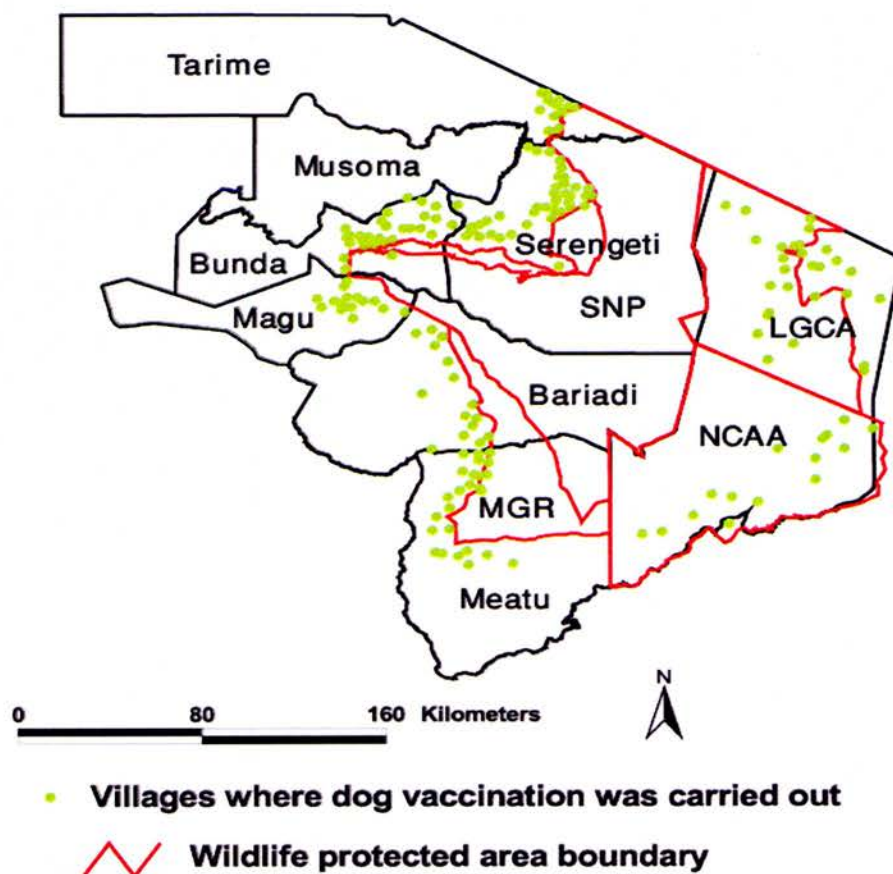


Figure 2. 2: Map showing location of study districts and villages in relation to boundaries of wildlife protected areas in the Serengeti ecosystem



2.2.3. Cultural settings

The community in the study area comprised two distinct ethnic groups represented by Kurya and Sukuma, two of the major tribes living in north-western Tanzania. The Sukuma people are the largest ethnic group in Tanzania, numbering more than 13 million among the population of Tanzania of 36 million and still retain a strong cultural identity. The Kurya is the second largest tribe in Mara region and the only dominant tribe in Tarime and Serengeti districts, two of the districts in the present

study. Although Kurya are traditionally cattle herders, their land area is increasingly restricted and agriculture has taken over as a primary occupation. Nonetheless, cattle remain ritually and socially important, for example in all marriage negotiations, where the bride wealth (dowry), paid for in cattle, remains the norm. Other minor tribes present in the study area were grouped into one category referred to in here as “others”. These included the Jita, Luo, Ikizu and Zanaki tribes.

2.2.4. Implementation of rabies vaccination programme

The first mass vaccination campaign was carried out in the vaccination zone in collaboration with district veterinary offices from June 2003 to September 2003, the second campaign from June 2004 to September 2004 and the third campaign from June 2005 to October 2005. A central point vaccination strategy was adopted for all villages within the vaccination zone. The date of the vaccination was communicated to dog owners at least one week before through official letters to village authorities which included village and sub-village chairpersons. Posters about the vaccination day were posted in all popular places in a village including schools, shops, markets, courts, political party and village offices. One day before the vaccination a reminder was sent to the villagers using an advertising team which delivered the information to schools and village leaders in order to encourage children to bring dogs for vaccination. Dog owners were asked to bring all dogs to a centrally located point in a village for vaccination. In the advertisements dog owners were informed that the vaccination was provided free of charge.

In year 2005 of the vaccination campaign the study evaluated the impact of different advertisement strategies on vaccination coverage by comparing the use of megaphone in comparison with the conventional approach used by district veterinary offices which include distribution of letters, vaccination day posters and word of mouth.

On the vaccination day a team of four people was stationed at a static central vaccination point from 0900. Each member in the team was assigned a specific task. The tasks included dog registration, certificate writing, and vaccine administration by injection. Dogs brought to the vaccination point were sub-cutaneously injected with one millilitre (ml) of an inactivated rabies vaccine (Novibac Rabies[®] Intervet,) and live attenuated multivalent vaccine (Novibac DHP[®] Intervet) containing CDV, CPV and CHV vaccines for years 2003 and 2004, whereas for year 2005 the DHP vaccine was replaced with the DP vaccine (Novibac Puppy DP[®] Intervet) containing only CDV and CPV vaccines. A vaccination certificate was given to the dog owner, and a coloured plastic collar tied on the neck of each vaccinated dog.

Disposable needles and syringes were used. Needles were used only once for each dog while syringes were recycled for every 20 dogs. 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. The age of dog given by owner was validated by person doing the registration by asking owners to correlate the age of the dog with an important memorable event in a household, village or region, such as the start of farming season, opening of schools, when a child started a particular class

in school, village election time, famine or other memorable events. This was done with the help of a local assistant from each village who was always present at a central vaccination point. The team remained at the vaccination point until no more dogs were forthcoming for one hour.

2.2.5. Household cross sectional and longitudinal questionnaire survey

2.2.6. Questionnaire design

The study used an open ended questionnaire whereby respondents were allowed to frame their own responses and hence permitted free expression of their own experience about the variable under investigation. Questions were carefully worded to avoid ambiguity and the language used was simple and non-technical. Leading questions were avoided as much as possible with each question containing only one idea in order to avoid confusing respondents. Questions were sequenced logically as far as possible starting with general questions for each variable under investigation then followed successively by more detailed and specific questions. The questionnaire was standardized, interviewers were not allowed to introduce additional items and their role was largely limited to content of the questionnaire. All probes introduced were recorded and respondents' answers were recorded as being a result of probing. In order to assess the effectiveness of the questionnaire as a measuring instrument, a pilot survey with the proposed questionnaire was conducted by interviewers in one study village and results were evaluated as to the relevance, completeness and accuracy of the questionnaire. Questions which did not accurately measure the intended information were modified and where necessary new questions were added to improve the questionnaire as a measuring tool.

Four interviewers were identified and trained as thoroughly as possible by the author prior to starting the questionnaire survey in order to minimize variation among interviewers. The importance and need for questionnaire standardization was emphasized and interviewers were trained to ask each question as it was worded on the questionnaire form.

One week before the scheduled vaccination day, a pre-vaccination questionnaire survey was conducted within the vaccination zone study villages. The survey was conducted only once throughout the study period in order to collect baseline information on household socio-economic status, level of education, dog keeping practices rabies awareness, perception and attitudes. The survey for the pre-vaccination household questionnaire was conducted by the author and one other trained interviewer. For all household questionnaire surveys the World Health Organization (WHO) expanded programme on immunization (EPI) cluster survey method was initially adopted (Myatt *et al.*, 2005; Lameshow & Robinson, 1985; Henderson & Sundaresan, 1982), but later rejected because of practical difficulties associated with spatial distribution of households in the study villages. The EPI clusters approach assumes household sampling along a line transect whereas in this study the spatial distribution of households in the study area did not follow any of the line transects that were established for household sampling purposes. Data collected from the cluster approach were not included in the analysis. As an alternative, the questionnaire was administered to a unit of 10 to 15 households in each village (locally identified as the ten-cell unit). The ten-cell units in each sub-village were



obtained by random sampling from a list of all ten-cell units present in a sub- village. The sub-villages represented a range of distances from the location of the vaccination station in the village centre. Whenever possible the head of household was interviewed but in absence of head of household any adult (above 18 years) was interviewed. Re-visits were conducted if no household member could be interviewed at the first visit. If no household member could be located and interviewed after subsequent re-visits, another household was randomly selected and interviewed. The pre-vaccination questionnaire used in the survey is included as Appendix I.

Within a month of the vaccination day, a post-vaccination household questionnaire survey was administered in each study village. Households for the post-vaccination survey were selected using the ten-cell unit approach as for the pre-vaccination questionnaire survey. Information was collected on household characteristics including number of people and tribe, dog and livestock ownership, dog keeping practices and management, dog demography and dog vaccination status. Dogs owners were asked to produce vaccination certificates in order to identify dogs which were vaccinated in the present vaccination campaign. Dog vaccination status was also confirmed by observation of coloured plastic collar fitted on the vaccination day. For unvaccinated dogs, owners were asked to explain the reasons why their dogs were not vaccinated. The Geographical Position System (GPS) location for each household was recorded. In order to evaluate the consistency of the respondent's answers, the same questionnaire was re-administered to the same respondents within seven days from the previous interview. The post vaccination questionnaire used in the survey is included as Appendix II.

2.2.7. Factors influencing vaccination coverage

Evaluation of the impact of various factors on vaccination coverage in the study was conducted using data collected in the first vaccination campaign (year 2003) in order to avoid bias that was likely to be introduced if data collected in subsequent vaccination campaigns were used.

2.2.8. Direct observation of collared dogs

Within one to three days after the vaccination campaign in each study village, one person travelled along all major roads, garbage points and popular centres to observe the proportion of collared and un-collared dogs in order to observe unrestricted family, neighbourhood and feral dogs present in the population. Direct observations were carried out from 1700 to 1900 and 0630 to 0830 as unrestricted and feral dogs are likely to be more active when human activity is low and the weather is cool. Direct observation was carried out in daylight to allow for better visibility of dogs.

2.2.9. Estimation of vaccination coverage

Vaccination coverage of dogs was estimated from several sources of data: a) from the household questionnaire survey as the proportion of vaccinated to unvaccinated dogs in households b) from directed observation of collared and uncollared dogs and c) from doses of vaccine used as a proportion of the total dog population estimated from the dog-to-human ratio for year 2003. The human population was determined from the 2002 national census data for each village and projected at 2.9% annual growth rate (Tanzania National Bureau of Statistics, 2005). The vaccination coverage

observed from the three different sources of data was then compared to evaluate consistency in coverage and the proportion of feral dog population that is likely to be inaccessible for central point parenteral vaccination.

To further explore the proportion of feral dogs a question was included in the household questionnaire survey in order to assess the proportion of households that reported sightings of unrestricted family, neighbourhood and feral dogs. Heads of households were asked whether they had ever observed any unrestricted family, neighbourhood or feral dog in the village, the number of dogs they had observed and the frequency of observation per week. Because of the likelihood of respondents reporting the same dog more than once, the number of dogs reported was not used in the analysis. Instead, the proportion of households that reported sightings of unrestricted family, neighbourhood or feral dog was used as an index of degree of feral dogs' problem in a village. The proportion of feral dogs was also assessed by comparing vaccination coverage obtained by household questionnaire survey and direct observation of collared dogs.

2.2.10. The influence of household prior knowledge of rabies

In order to investigate the impact that prior knowledge of rabies had on vaccination coverage, the study compared vaccination coverage in households visited in the previous year's questionnaire survey with that achieved in newly selected households that were not visited for the questionnaire survey in the previous year. Previously-visited households were assumed to have more prior knowledge and awareness about

rabies than newly selected households as a result of the formers' interaction with interviewers in the previous year. Vaccination coverage was estimated as described previously.

2.2.11. The influence of publicity on vaccination coverage

In order to investigate the influence of publicity on vaccination coverage the study compared two approaches: i) the conventional approach of dissemination of vaccination day information used by district veterinary offices on vaccination day, including distribution of leaflets, posters and letters to village leadership and word of mouth. This strategy, which is referred to here as minimal publicity, involved distribution of leaflets, posters and letters to each village a week before the earmarked vaccination day informing all owners to bring dogs to a static central location in a village for vaccination. The information was posted at all popular places in a village including schools, political party offices, shopping centres and government offices. In addition information was passed to villagers by village leaders in formal and informal meetings instructing all owners to bring dogs for vaccination on a specified day and location. ii) a combination of the previous approach together with intensified use of a special advertisement team which delivered information about the vaccination day across a village using a megaphone. This strategy, referred to here as intensive publicity, involved the use of a combination of minimal publicity and a specialized advertisement team, with a vehicle and megaphone, which visited each village one day before the vaccination to deliver the information across the entire village using a megaphone. Vaccination

coverage achieved in the two strategies was estimated and compared as previously described.

2.2.12. Dog and livestock ownership, dog restriction status, function and source

Data were collected in the cross sectional household questionnaire survey on the extent to which dog owners restricted the movement of their dogs. Dog owners were asked whether or not they restricted their dogs, how the dogs were restricted (e.g. use of fence, rope or other methods) and the time period during which dogs were restricted. Information was collected on dog function by asking dog owners the reasons why they keep dogs as classified by companion, home security, livestock security and hunting. Data were also collected on the sources where dog owners obtain dogs, either as: i) neighbouring village if dogs were not obtained from the same village and ii) same village if dogs were obtained from the same village including the same household. Information on the number of livestock owned by each household was obtained from the cross-sectional household questionnaire survey explained previously. Data were collected on the number of livestock owned by a household which included cattle, goats and sheep and the relationship between livestock and dog ownership investigated.

2.2.13. Community rabies awareness, attitudes and perception

Data were collected on community awareness, attitudes and perception to rabies within the vaccination zone study villages described above using household pre-

vaccination questionnaire survey. Households were visited at least a week before the vaccination day in each village and information collected on basic knowledge about rabies, the mode of transmission to dogs and humans, preventive measures against rabies for dogs and humans, handling of dogs within households and rabies awareness. Rabies awareness was classified into four categories based on the precision in describing the mode of transmission to human and preventive measures for both dog and human. Heads of households who described correctly both the mode of transmission to humans and animals and preventive measures for both human and dogs were classified into high rabies awareness category; those who could not fully describe either of the two were classified into the medium rabies awareness category; heads of households who described only either the mode of transmission or preventive measures were classified into the low rabies awareness group and those who could not describe any of the two were classified as unaware.

2.2.14. Socio-economic status

Information was also collected on household socio-economic status. To avoid using socio economic indicators which are likely to be insensitive to local determinants of wealth the study used wealth indicators originally identified in the zone through Rapid Rural Appraisal (RRA) approaches (VIC Mwanza-DFID, 1999). The wealth ranking survey identified the number of cattle, agricultural implements (in particular ploughs-proxy for acreage cultivated) and quality of house as key indicator of wealth in the region. These criteria for socio- economic status were based on productive capability, command for money and housing standards. Housing quality and number

of cattle owned were also independently used as wealth indicators because although individuals may own a large number of cattle and hence considered to be wealthier they may not necessarily own “modern” houses constructed with cement blocks and corrugated iron sheets. Individuals who owned houses constructed of cement block roofed with corrugated iron sheet and the floor cemented were categorized as belonging to high socio-economic status; those owning houses with baked brick walls, thatched roofs and cement or earth floors were grouped into medium socio-economic status, those with earth bricks and thatched roof were classified in low socio economic status and those owning houses with mud walls and thatched roof were grouped into the poor socio-economic status group. Regardless of housing quality, individuals owning more than 100 head of cattle were categorized as belonging to high socio economic status, those with 50 to 100 heads were classified into the medium socio economic status, household with 5 to 49 heads of cattle were classified into low socio- economic status and households with less than 5 heads of cattle were classified as poor. Further information was collected on education level and religion.

2.2.15. Confidence intervals

Confidence intervals in this chapter were calculated using EpiInfo 6 software Version 6.04d (Centre for Disease Control & Prevention, USA, 2001). Confidence intervals cited in parentheses are 95% exact binomial and confidence intervals are plotted on graphs.

2.2.16. Data analysis

Data analysis was conducted using the R software version 1.8.1- ISBN 3-900051-00-3 (The R Foundation for Statistical Computing, 2003) as either either univariate or multivariate mixed effect models depending on the variables under investigation and sampling level. In order to investigate factors which influence vaccination coverage, data were analysed at three levels: i) the village level ii) household level and iii) individual dog level. The data were analysed using a linear mixed effect model with binomial errors. At the village level, distance from district headquarters, distance from the nearest district hospital and village population size formed the fixed effects with district as a random effect; at the household level fixed effects included number of livestock owned, number of dogs owned, number of people in a household, distance from a central vaccination point to a household with district and village as random effects. At the dog level the fixed effects included dog age class, sex and whether a dog is restricted or not and random effects included district, village and household. The influence of publicity strategies on vaccination coverage was investigated using mixed effect model with district and village as random effects.

The Geographical Position System (GPS) locations for each central vaccination point, each household interviewed and each district hospital were recorded using Garmin GPS Plus III. The GPS fixes were then used to estimate the Euclidean distance for each village from the nearest district hospital, district head quarters and the distance of each household from the central vaccination point in a village. Since usually individuals living within 10 km from the district headquarters do not pay for

public transport, distances from nearest district hospital and headquarters were categorized as near if ≤ 10 km and far if > 10 km.

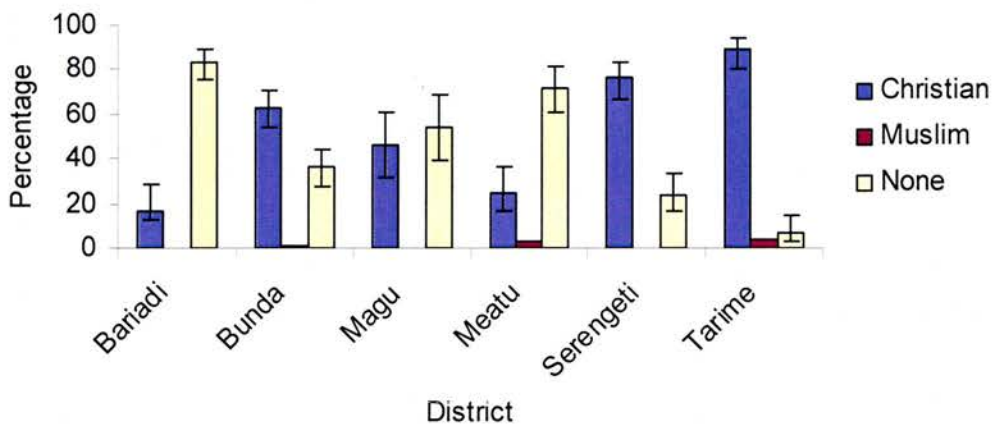
2.3. Results

2.3.2. Description of the study population

2.3.3. Community rabies awareness and attitudes

Overall the community in the vaccination zone was predominantly Christian 53.4% (49.3-57.5%) whereas 45.4% (41.3-49.5%) were not affiliated to any popular religious denomination and 1.2 % (0.5-2.5%) were Muslims (Figure 2.3).

Figure 2. 3: Community religion affiliations in the study villages within the vaccination zone determined from the post-vaccination household questionnaire



Out of 352 heads of household interviewed 99.31 % (98.25-99.81%) were able to describe the basic and major rabies mode of transmission and how the disease can be prevented in both dogs and human by vaccination of dogs and treatment at hospital for humans. On the role of wildlife and dogs as transmitters of rabies, only 0.85% (0.2-2.5%) of heads of households mentioned wildlife as rabies transmitters to human with the remaining proportion mentioning domestic dogs as the transmitter. Of all heads of households interviewed 98% (96.4-99 %) indicated willingness to

bring their dogs for vaccination to a centrally located point in a village if the vaccine was provided free of charge and 9.3% (7-12%) indicated that they would not bring their dogs for vaccination if the vaccine was provided at a cost.

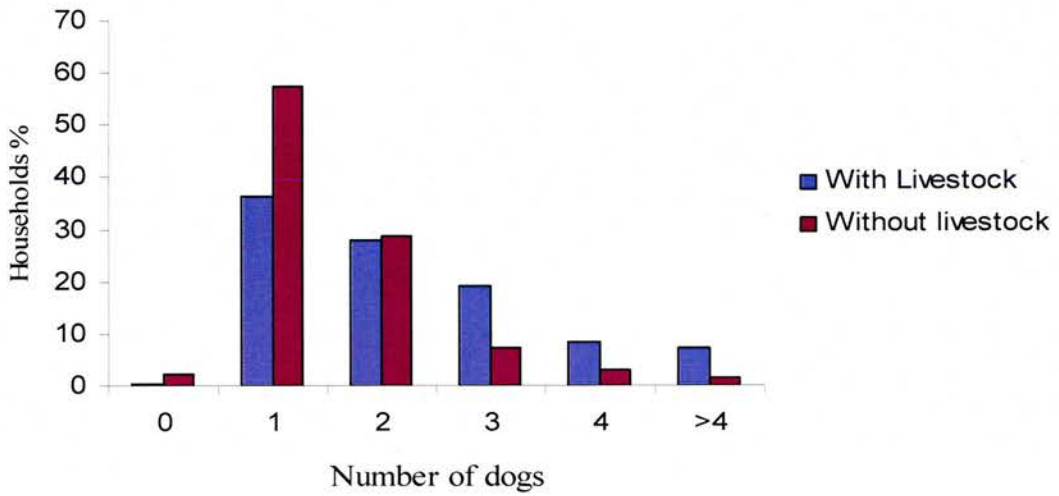
2.3.4. Dog and livestock ownership

Overall a greater proportion of household with livestock (84.5 %; range 82.63-86.22%) owned dogs in comparison with those that did not own livestock. Out of 1349 owned dogs only 8.5% (7-10%) were restricted at least for sometime during day time. All restricted dogs were released at night. Livestock and dog ownership for each district is indicated in Table 2.2 and Figure 2.4.

Table 2. 2: Livestock and dog ownership by households in six districts of the vaccination zone year 2003

District	Total number of households	Proportion of households with livestock (%)	Proportion of dogs owned by household with livestock (%)
Bariadi	342	61.4	84.2
Bunda	136	64	78.4
Magu	333	52.2	78
Meatu	314	62.4	75.5
Serengeti	135	66	91.5
Tarime	194	62.4	82.3

Figure 2. 4: Proportion of households with dogs determined from the post vaccination household questionnaire



2.3.5. Proportion of feral dogs

Out of 1455 households interviewed in year 2003 questionnaire survey 6.2% (5-7.5) reported observation of dogs which could not be associated to any household in a village (feral dogs) whereas 96.2% (92.6-97.7) of the 1455 households interviewed reported that most dogs seen in a village are known and could be associated to specific households (non feral dogs).

2.3.6. Acquisition of new dogs by household

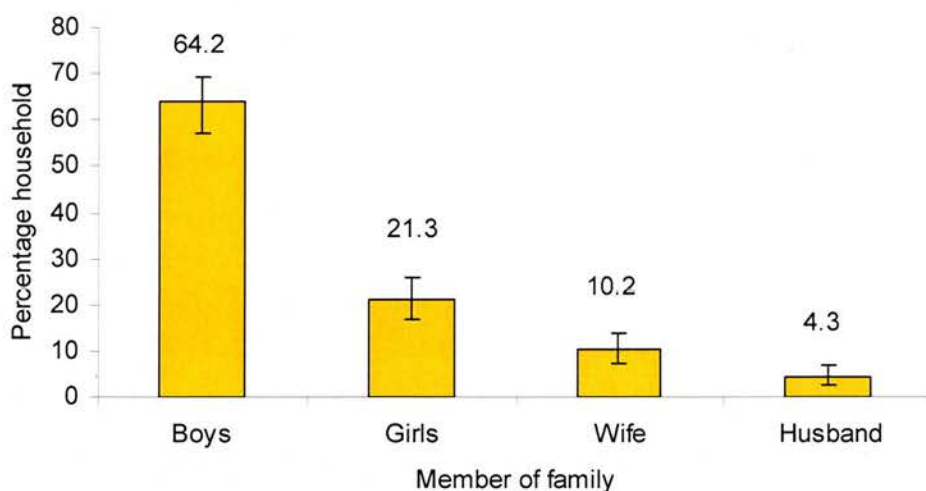
Out of 1562 owned dogs recorded in the 2003 questionnaire survey 82% (80.88-84.68) were acquired from within their own village and the remaining proportion acquired from other neighbouring villages and thus 18% (16.2-20.1) acquired from

other neighbouring villages. Out of all new dogs acquired 85% (82.3- 87.6) were puppies, reflecting preference of dog owners to acquire puppies to other age classes.

2.3.7. Household principal dog handler

The proportion of households reporting dog handling practices by member of household is illustrated in Figure 2.5. Overall, 85.5% (81.4-89%) of the households reported children as the family members who handle dogs more frequently. Children were categorized as those below the age of 15 years. All individuals above this age were categorized as adults.

Figure 2. 5: Age and gender of principal household dog handler for the 352 households interviewed in the pre-vaccination household questionnaire



2.3.8. Factors influencing vaccination coverage

The overall factors influencing vaccination coverage and their respective statistical significant are illustrated in Tables 2.3 and 2.4.

2.3.9. Village factors influencing vaccination coverage

From questionnaire data, the overall vaccination coverage of owned dogs for 2003 across the entire vaccination zone was 80.3% (78-82.4%) and for 2004 was 81% (79-83%). Vaccination coverage achieved in the six study districts villages for years 2003, 2004 and 2005 is demonstrated in Figure 2.6. The drop in coverage in year 2005 observed in Magu, Bunda and Serengeti district was due to changes made in the advertisement approach whereby the use of megaphone was withdrawn in these districts in order to test the impact of different publicity approaches (see section 2.2.10). Evaluation of the results demonstrated no significant difference in vaccination coverage as estimated from the household questionnaire survey, direct observation of collared dogs and doses of vaccine used as a proportion of the total dog population estimated from dog- to-human ration ($F_{2, 10} = 2.7, p= 0.11$). There was no significant difference in vaccination coverage between districts ($F_{5, 6} = 0.9, p= 0.54$). Estimation of vaccination coverage in the 2004 campaign showed no significant difference in vaccination coverage between households that had been visited in 2003 for questionnaire survey and new households ($F_{1, 1046} = 2.04, p= 0.15$). The overall coverage in households visited in year 2003 was 85.2% (83.4 to 86.8%) and for newly visited household was 88.26% (85.47 to 90.68 %).

Table 2. 3: Univariate analysis of factors influencing vaccination coverage

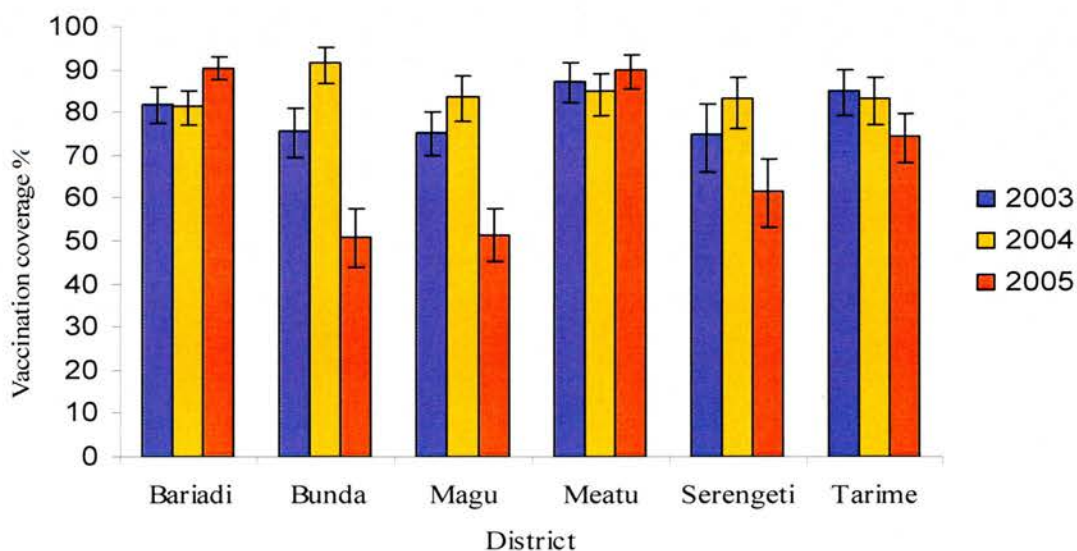
Table 2. 3: Univariate analysis of factors influencing vaccination coverage

Factor	p value
Vaccination coverage estimation approach (direct observation of collared dogs, questionnaire survey, number of vaccine doses used)	$F_{2,10} = 2.7, p= 0.11$
Publicity approach (Intensive and minimal publicity)	$F_{1,4} = 16.1, p= 0.01$
Household prior knowledge	$F_{1,1046} = 2.04, p= 0.15$
Tribe	$F_{4,1362} = 0.8, p=0.52$

Table 2. 4: Household level multivariate analysis controlling for district and village effects

Factor	p value
<i>Village level analysis</i>	
Distance from district headquarters	$F_{1,4} = 6.14, p= 0.07$
Distance from nearest district hospital	$F_{1,4} = 0.9, p= 0.39$
<i>Household level analysis</i>	
Number of dogs per household	$F_{1,684} = 0.16, p= 0.69$
Number of Livestock per household	$F_{1,684} = 0.21, p= 0.65$
Number of people per household	$F_{1,684} = 0.04, p= 0.84$
Socio-economic status	$F_{1,684} = 0.24, p= 0.78$
Rabies awareness	$F_{3,684} = 0.18, p= 0.72$
Distance of household from central vaccination point	$F_{1,684} = 5.3, p= 0.02$
<i>Dog level analysis</i>	
Sex of dog	$F_{1,599} = 1.6, p= 0.21$
Dog age class	$F_{2,599} = 158.4, p < 0.0001$
Dog movement restriction status	$F_{1,599} = 0.36, p= 0.55$

Figure 2. 6: Over all vaccination coverage levels achieved in 6 study villages for year 2003, 2004 and 2005 vaccination campaigns estimated by household questionnaire survey



2.3.10. Vaccination coverage in relation to distance from district headquarters and district hospital

Vaccination coverage in relation to distance from district headquarters and nearest district hospital is illustrated in Figures 2.7 and 2.8. There was no significant difference between villages located near and far from district headquarters and hospitals ($F_{1,4} = 6.14, p = 0.07$ and $F_{1,4} = 0.9, p = 0.39$ respectively).

Figure 2. 7: Vaccination coverage in relation to distance from district headquarter estimated from household questionnaire survey

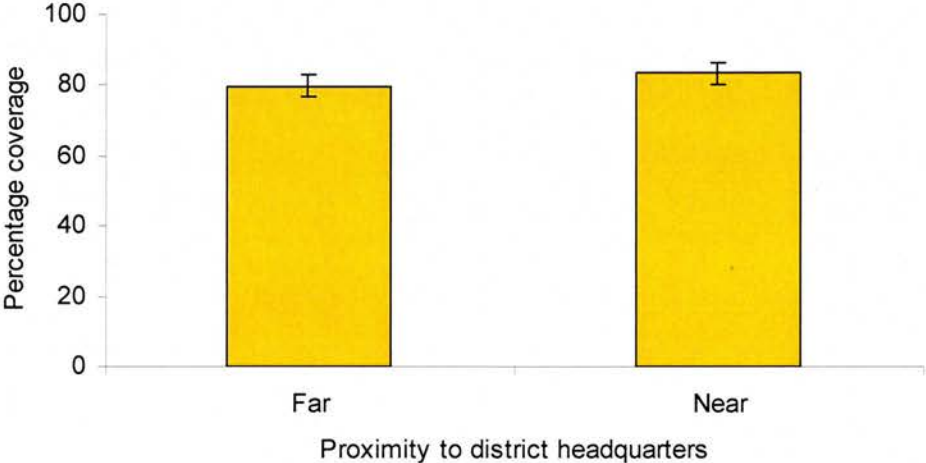
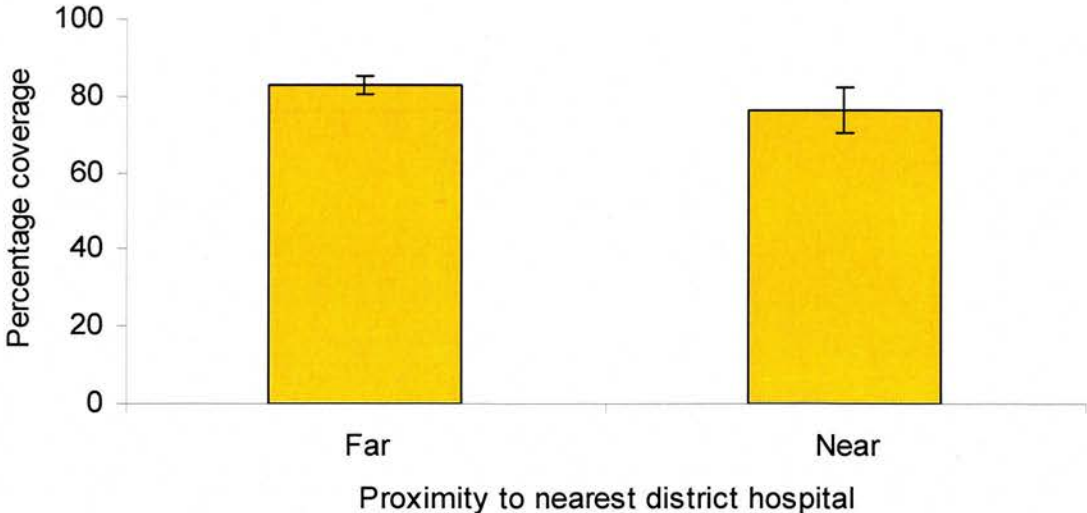


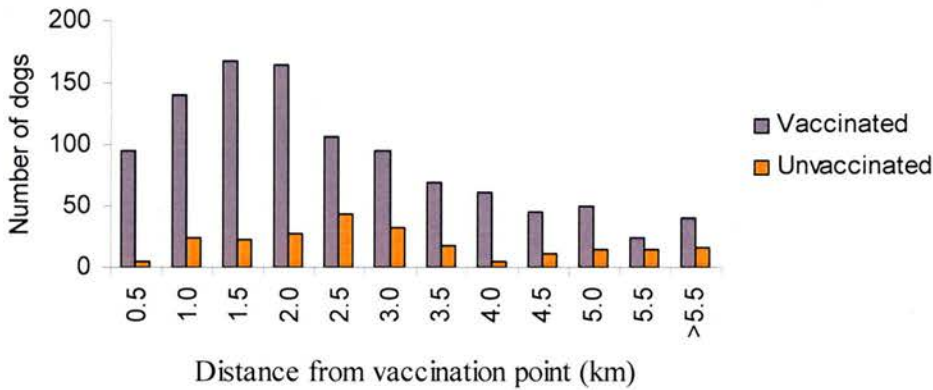
Figure 2. 8: Vaccination coverage in relation to distance from the nearest district hospital



2.3.11. Distribution of vaccinated and unvaccinated dogs with distance from central vaccination point

The distribution of vaccinated and unvaccinated dogs with distance from the central vaccination point is shown in Figure 2.9 reflecting more vaccinated than unvaccinated dogs across the whole distance range from 0.5 to over 5.5 km

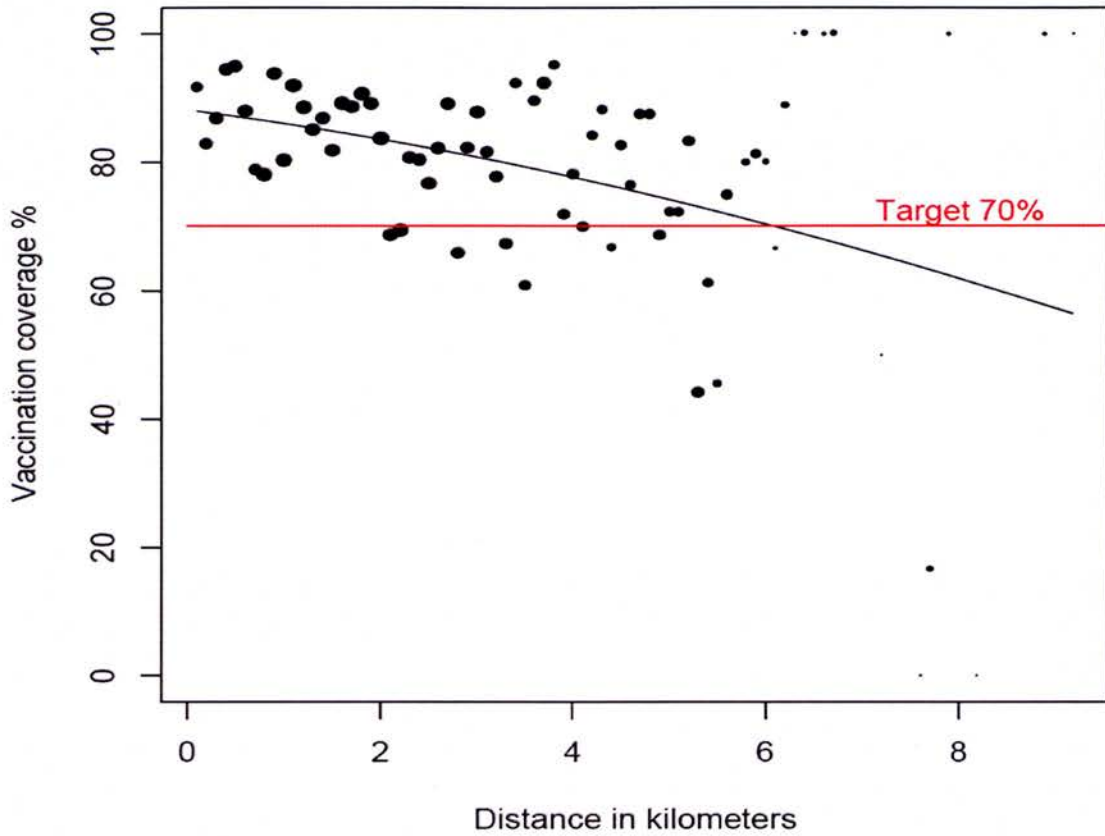
Figure 2. 9: Distribution of vaccinated and unvaccinated dogs with distance from the central vaccination point estimated from household questionnaire survey



2.3.12. Household vaccination coverage with distance from the vaccination point

For the 12 study villages the average vaccination coverage for year 2003 decreased significantly with distance from the central vaccination point ($F_{1, 684} = 5.3, p = 0.02$) (Figure 2.10), although the vaccination coverage was generally greater than 70% even 5 km from the central vaccination point.

Figure 2. 10: Vaccination coverage plotted against distance from the central vaccination point and a logistic regression with binomial errors fitted to the proportional data. The target coverage of 70 % recommended to control dog rabies is marked with a red line. The black dots represent number of dogs.

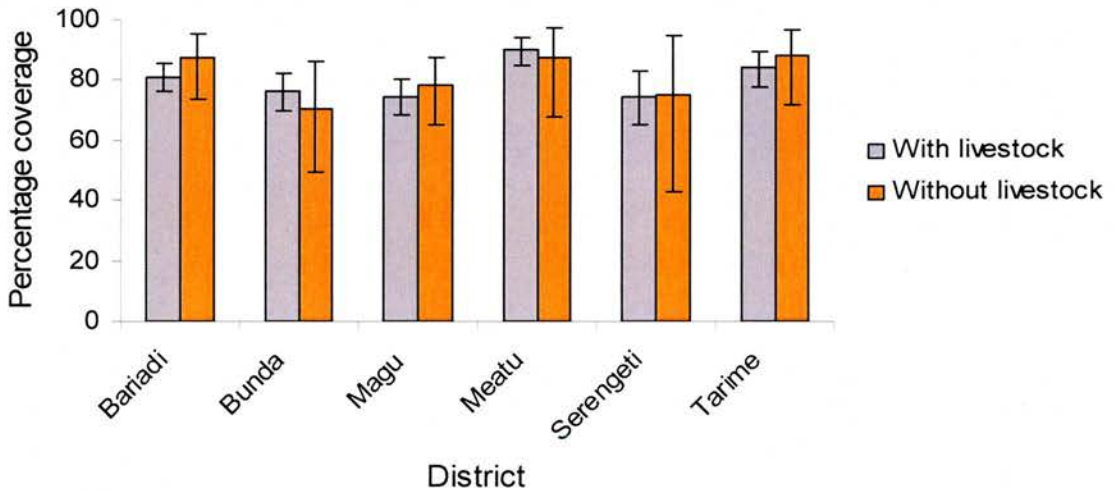


2.3.13. Vaccination coverage in relation to livestock ownership

Although a significantly greater proportion of households with livestock owned dogs in comparison with those that did not own livestock ($\chi^2 = 290.58$, d.f. = 1, $p < 0.0001$), the number of livestock owned did not affect the probability that a dog was vaccinated ($F_{1, 684} = 0.21$, $p = 0.65$), with vaccination coverage in livestock-owning households at 80% (78-83) compared to 82 % (76-87) in household with no

livestock. Vaccination coverage in households which owned livestock and those which did not is shown in Figure 2.11.

Figure 2. 11: Vaccination coverage in households which own livestock and those which do not own livestock estimated from household questionnaire survey



2.3.14. Vaccination coverage level within major ethnic groups and in relation to socio- economic status

Coverage was high irrespective of the socio-economic status with no significant differences observed ($F_{1, 684} = 0.24, p= 0.78p=0.6$), however coverage was more variable among households with low socio-economic status. Similarly, no significant differences were detected between different ethnic groups ($F_{4,684} = 0.8, p=0.52$). Tribes not belonging to the major ethnic groups in the vaccination zone were demonstrated to have a vaccination coverage of 93.4% (84.05-98.2) which was not significantly higher than the coverage of 83.1% (80.51-85.5) in Sukuma and 84.67% (80.82-88.01) in Kurya ethnic groups.

2.3.15. Dog factors influencing vaccination coverage.

Dogs' sex did not have any significant effect on vaccination coverage ($F_{1, 599} = 1.6$, $p = 0.21$). Dog age-class had a significant influence on vaccination coverage ($F_{2, 599} = 158.4$, $p < 0.0001$) with significantly fewer puppies vaccinated 24.7% (17.14-33.78) compared to juvenile 82.9% (78.9-86.4) and adult dogs 86.6% (84.1-88.86). There was no significant difference in vaccination coverage between restricted and unrestricted dogs ($F_{1, 599} = 0.36$, $p = 0.55$). Dog factors influencing vaccination coverage are shown in Figures 2.13 and 2.14.

Figure 2. 12: Age specific vaccination coverage according to dog age classes estimated from household questionnaire survey

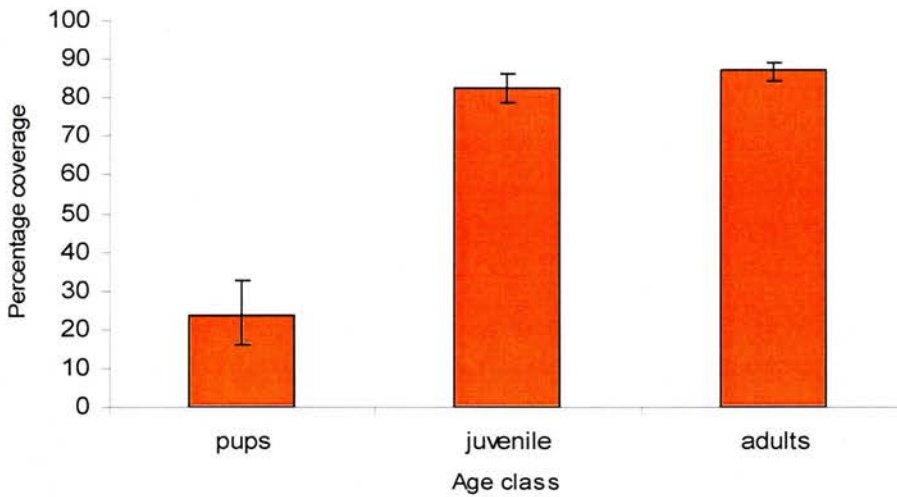
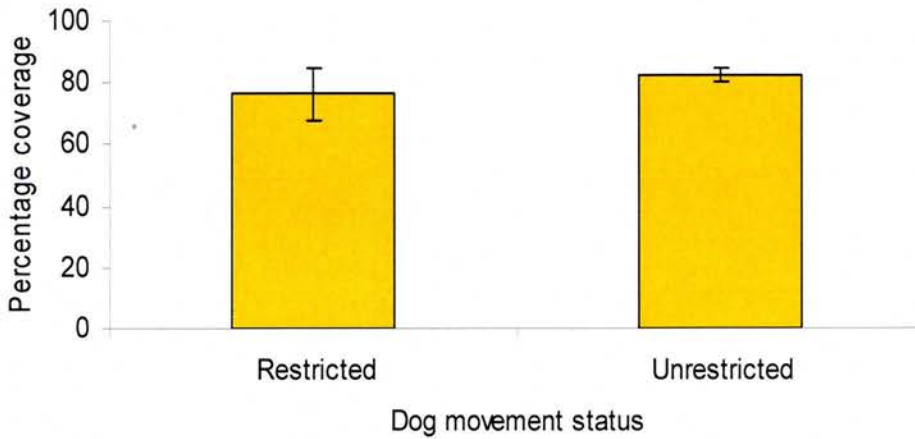


Figure 2. 13: Vaccination coverage achieved in restricted and un- restricted dogs estimated from household questionnaire survey reflecting no significant difference between the two categories



2.3.16. The influence of publicity on vaccination coverage

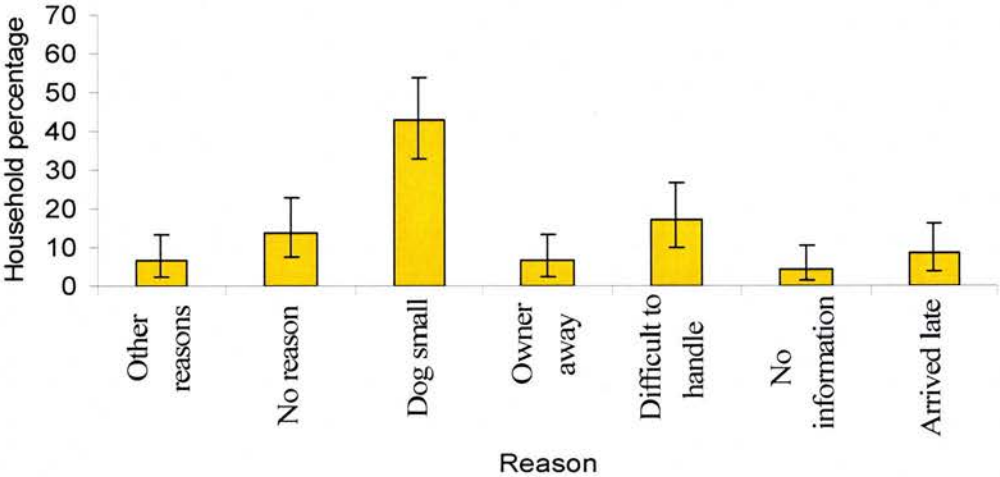
Publicity strategy had a significant effect on vaccination coverage ($F_{1, 4} = 16.1, p = 0.001$) with the minimal publicity strategy achieving a lower coverage of 53.5% (49.5 to 57.4) compared to 98.8% (97.9 to 99.4) for the intensive publicity strategy.

2.3.17. Reasons for not bring dogs to a central vaccination point

The major reason cited 43% (32.8-53.7%) for failing to bring dogs for vaccination was young age (dogs ≤ 3 months old) and this was significantly higher than for any other reason. The proportion of households citing young age of dogs as the reason for not vaccinating their dog was significantly higher than for any other reason ($F_{2, 599} = 138.4, p < 0.0001$, Figure 2.15). Other reasons included the dog being difficult to

handle 17% (10.2-26.4), negligence 14% (7.66-22.72), arriving late at vaccination point 8.6% (3.8-16.25), dog owner being away from home 6.45% (95% 2.4-13.5) as well as other diverse reasons(funerals, sickness, dog not at home) 6.45% (2.4-13.5). Proportion of households and the reasons for not vaccinating dogs is illustrated in Figure 2.14.

Figure 2. 14: Explanations given for not bringing dogs for vaccination as described in the household questionnaire survey



2.4. Discussion

This study has demonstrated that a central point vaccination strategy is effective as a dog vaccination strategy in rural Tanzania. The strategy achieved high vaccination coverage, over that recommended for rabies control that is robust to a wide range of social, cultural and economic factors. The high vaccination coverage level achieved in the first campaign was maintained in the subsequent two years of the vaccination campaign across the entire vaccination zone. Results suggest that the most important factors that are likely to compromise vaccination coverage are exclusion of puppies and the distance of households from the central vaccination point. However with intensive dissemination of information about rabies vaccination day, and proper involvement of local village community leaders, the influence of age of dog and spatial distribution of households is likely to be minimized and sufficient vaccination coverage in this socio-economic setting can be achieved.

Vaccination coverage estimated from the household questionnaire survey, direct observation of collared and uncollared dogs and doses of vaccine used as a proportion of the total dog population estimated from dog-to-human ratio, did not differ. These results suggest that household questionnaire surveys are representative of total dog population vaccination coverage and that there are apparently few “ownerless” dogs, inaccessible for central point parenteral vaccination in this setting. Although free-ranging dogs were reported in the household questionnaire, most of these dogs were known to the community and could be associated or linked with a particular household. This is contrary to the long held belief of presence of large

number of inaccessible dogs in the population, which has been used to justify culling of dogs as a strategy for rabies control. The finding of this study reinforces those of other studies that the number of dogs that are inaccessible for parenteral vaccination in most communities of the developing world is generally low and unlikely to have any substantial impact on rabies control through parenteral vaccination (World Health organization, 2004)..

In this study, most new dogs were acquired as puppies from within the village, and there was little immigration of dogs from outside the villages. Birth and death rates therefore remain the major demographic factors which are likely to influence the dog population turnover and hence temporal decline of vaccination coverage. In dog populations with high turn over rate instantaneous vaccination coverage is likely to decline rapidly as a result of rapid recruitment of new unvaccinated dogs.

Within the agro-pastoral vaccination zone pre-vaccination rabies awareness was high with most individuals knowledgeable on how rabies is transmitted from animal to animal and from animals to human and preventive measures that are required against rabies in both humans and dogs. The high awareness of rabies within the community is likely to have contributed substantially to the high vaccination coverage levels achieved in this study. The observed high rabies awareness in this study is likely to be similar in most agro-pastoral rural communities in Tanzania because of wide social and cultural similarities among the rural agro-pastoral communities across the country, but may be different in remote pastoral communities in Tanzania, or other cultural settings in other countries. .

The findings of this study indicate that children and boys in particular, are the member of households who are likely to handle dogs. Indeed, the key role of children in bringing dogs to central vaccination points has been underscored in a number of studies (de Balogh *et al.*, 1993; Kitala *et al.*, 2001; Cleaveland *et al.*, 2003). Children under 15 years old are also at higher risk of dog bite than older age classes (Fevre *et al.*, 2005; Agarwal & Reddajah, 2004; Eng *et al.*, 1993). Targeting children for rabies educational information and vaccination campaign advertisements therefore needs to be considered as one of the important strategies in order to increase the accessibility of dogs to a central vaccination, as frequently handled dogs are more easily taken to vaccination points (Knobel, pers comm), but at the same time reducing the incidence of rabies among children.

Although unrestricted dogs achieved slightly higher coverage rates than restricted dogs, this difference was not significant. The results presented here therefore suggest that lack of dog confinement, although generally regarded as a factor that will decrease the probability of a dog being vaccinated, is not necessarily an indication of accessibility of dogs for central point parenteral vaccination.

Dogs less than or equal to three months of age were less likely to be vaccinated than older dogs, a finding that is consistent with other studies (Kitala *et al.*, 2001; Cleaveland, 1996; Coleman, 1999; Kongkaew *et al.*, 2004). Despite intensive publicity encouraging owners to bring puppies for vaccination, puppy vaccination coverage remained consistently low throughout the three years of the vaccination

campaign indicating that dog owners are possibly still doubtful about the appropriateness of vaccinating puppies against rabies. Reasons for dog owners' doubts remain open for further investigation. However, the theoretical exclusion of puppies for rabies vaccination is primarily based on most vaccine manufacturers' recommendation and is based on the potential for interference with MDAs in puppies. This recommendation still forms an important component in rabies control policy for most countries in Africa and has been commonly practiced for a long time. As a result it is likely that the belief has been unknowingly deeply entrenched in dog owners' perceptions and attitudes for a long time. Coleman (1999) and Cleaveland (1996) argue in favour of including puppies in rabies vaccination programme in order to improve cost effectiveness. Given the fact that dogs less than six months old are both more important in rabies transmission to humans (Mitmoonpitak *et al.*, 1998) and more likely to be accessible for parenteral rabies vaccination than older dogs, the inclusion of pups in rabies vaccination is highly recommended. Improving the accessibility of puppies in vaccination programmes is likely to require considerably longer intensive community education than what could be afforded in this study. Furthermore puppies are known to suffer from the highest crude mortality rate of all age classes. For example in Kenya and in the present study, puppy mortality of up to 50% has been documented (Kitala *et al.*, 2001; Coleman, 1999). With such high background mortality rate in pups there is a potential danger that pups deaths may be erroneously linked to vaccination against rabies and hence community hostility against future rabies vaccination programmes may be generated. In addition inclusion of puppies is likely to result into considerable degree of apparent vaccine wastage due to the high mortality rate. In general terms, whereas

post vaccination immune response in puppies is unlikely to be a strong ground for the exclusion of puppies in rabies vaccination other likely important factors such as the cost-effectiveness of including puppies inclusion still need detailed investigation.

One of the factors likely to deter owners from bringing dogs for vaccination to a central point is the total number of dogs owned. Some owners may find bringing many dogs to central point a difficult undertaking and hence opt to vaccinate dogs that are considered more valuable. The present study however shows that number of dogs owned did not influence the chances of a dog being vaccinated indicating that dog owners are likely to vaccinate all dogs owned regardless of how many dogs they own.

Distance from the central vaccination point has been documented to have a significant effect on vaccination coverage (Cleaveland, 1996, Coleman, 1999) with vaccination coverage declining progressively with increasing distance from the central vaccination point. In small scale vaccination trials in rural Tanzania Cleaveland (1996) showed that the 70% coverage was likely to be maintained within a catchment area not exceeding 1 km from the central vaccination point. In the present study although coverage tended to decrease with distance from the central vaccination point it generally remained above the lower critical bound of 55% (Coleman & Dye 1996) to over 5.5 km of radius from the central vaccination point suggesting the potential for a wider vaccination catchment area. It must however be borne in mind that the influence of distance from the vaccination centre on coverage is unlikely to be a static phenomenon and is bound to depend largely on active

participation of local community which is a function of several factors including the degree of involvement of local leaders and intensive dissemination of information about the vaccination day. This is likely to be one reason for the difference observed between this study and those by Cleaveland (1996) and Coleman (1999).

**Chapter III: Evaluating the household level economic burden of rabies and
post-exposure prophylaxis seeking behaviour in rural Tanzania**

3.0. Introduction

Almost three decades after the Alma-Ata Declaration elevated health to the status of a basic and fundamental human right and explicitly recognized its relationship with economic development, human rabies cases are still on the rise in most parts of Africa (Cleaveland 1998, Perry 1993). The disease still remains one of the global public health challenges with substantial social and economic impact to the world's poor. Despite being controlled in most of the developed world, rabies is estimated to cause 55,000 human deaths annually in Asia and Africa alone with over 1.8 disability adjusted life years (DALY) lost annually (Knobel *et al.*, 2005). The World Health Organization (WHO) estimates that 10 million people, 99% in the developing world, receive the expensive PEP (World Health Organization, 2004). However, comparatively little attention and effort have been devoted to the control of the disease across the entire Africa and Asian region. One possible reason for this inadequate attention is lack of awareness of the disease burden in both human and economic terms among policy makers and practitioners.

Theoretical and meta-analysis studies have attempted to quantify the broader public health burden of rabies at national and regional levels in terms of the disability adjusted life years lost (DALY) (Knobel, *et al.*, 2005; Coleman *et al.*, 2004). These studies have demonstrated that rabies exerts a considerable public health impact with the burden of the disease disproportionately skewed towards children and segments of the population with low socio-economic status. However, little empirical information is available on the economic loss imposed by the disease, particularly in

quantifying the burden of rabies at the household level, despite this topic being of considerable interest in development and health economics. For example, household level burden for diseases such as malaria, tuberculosis and HIV/AIDS are well documented (Bates *et al.*, 2004; Chima *et al.*, 2003). For rabies, individual and household economic costs accrue through the cost of PEP and loss of productivity through lost work time.

Moreover, there are inextricable links between poverty and susceptibility to disease, with negative feedback loops a key feature (World Health Organization, 2002a). Several medical studies have highlighted the importance of diseases in household impoverishment. Sachs and Malaney (2002) for instance have documented a strong correlation between malaria and poverty and demonstrated that in communities where malaria is endemic, economic development is likely to be substantially impeded. Studies by the World Bank have shown that diseases are likely to be the most important cause of household poverty (World Bank, 2000). The economic impact of rabies at household level has however not been adequately investigated in comparison with other diseases such as malaria, tuberculosis and human immunodeficiency virus (HIV/ AIDS), although it is clear that susceptibility to rabies in poor communities is no exception not least because rabies is most commonly documented in rural communities (Knobel *et al.*, 2005), and these are generally the most impoverished in the developing world. Thus a measure of rabies burden at household level that is accessible and clear to policy makers is important in determining the impact of rabies to household economics, and, by extrapolation, to

the national economy. By comparing the economic burden of rabies with other diseases at household level, disease control efforts can be prioritized.

Furthermore studies that have investigated disease treatment costs and coping strategies at household level have shown that unbearable health costs are likely to deter or delay household health-care utilisation or encourage use of less effective health-care sources or practices, particularly by the poor (Sauerborn *et al.*, 1996., 1996b). For example, a recent review of the relationship between malaria and poverty (Worrall *et al.*, 2005) has shown that poor households are more likely to opt for medical care outside the mainstream health sector than wealthier households, and that the cost of malaria treatment, as well as distance to health facilities, were significant barriers to medical access for poor households. Health services, as a result, have been noted to be less effective in reaching the poor, less beneficial for the poor than the rich, and impose a heavier economic burden to the poor than rich (Fabricant *et al.*, 1999). These factors are likely to be relevant for rabies, a disease which has been documented to occur with higher incidence rates in poor community of rural areas than urban communities (Knobel *et al.*, 2005). Like with many other infectious diseases, delayed presentation to a health facility of bite victims from suspected rabid dogs is likely to be associated with increased risk of death. Detailed studies of treatment-seeking behaviour for some diseases such as tuberculosis and sleeping sickness have been documented (Odiit *et al.*, 2004; Wandwalo & Morkve 2000; Salaniponi *et al.*, 2000; Sherman *et al.*, 1999). However the treatment-seeking behaviour for rabies has not been adequately investigated.

One factor that is likely to increase the cost burden in treatment-seeking is the number of consultation encounters patients go through before proper medical care is provided. Studies that investigated tuberculosis treatment seeking-pattern in parts of the developing world have reported that patients are likely to go through a long treatment seeking pathway involving several encounters with different health providers including traditional, private and public sectors (Kamolratanakul *et al.*, 1999; Lonroth *et al.*, 2001a; Lonroth *et al.*, 2001b; Nair *et al.*, 1997; Wyss *et al.*, 2001). A study in Zambia for example has reported that patients may spend up to 6.7 health encounters prior to correct TB diagnosis at an appropriate health facility paying up to 10% of their monthly income in the process, for traditional healer consultation and ineffective herbal remedies (Needham *et al.*, 2004). In Tanzania tuberculosis patients have been reported to delay for up to a total of 185 days in reporting to a health facility for medical attention, with nearly 90% of this being patient's delay (Wandwalo & Morkve, 2000). In Uganda, up to 52% of sleeping sickness patients have been reported to be delayed for up to 60 days in reporting to a proper health facility for treatment (Odiit *et al.*, 2004). These observations in treatment seeking behaviour are, to a large extent, likely to apply to rabies and hence contribute an additional household burden.

Tanzania is one of the countries in the developing world that is classified as highly endemic for rabies (World Health Organization, 1989). Control strategies for rabies in the country have involved primarily domestic dog vaccination against rabies and PEP for human bite victims from suspected rabid dogs. The economic burden of rabies and treatment seeking pattern for bite victims from suspected rabid dogs has

never been investigated in the country and Africa as a whole. This study therefore forms the first attempt to explore the economic burden and treatment seeking pattern of rabies at a household level.

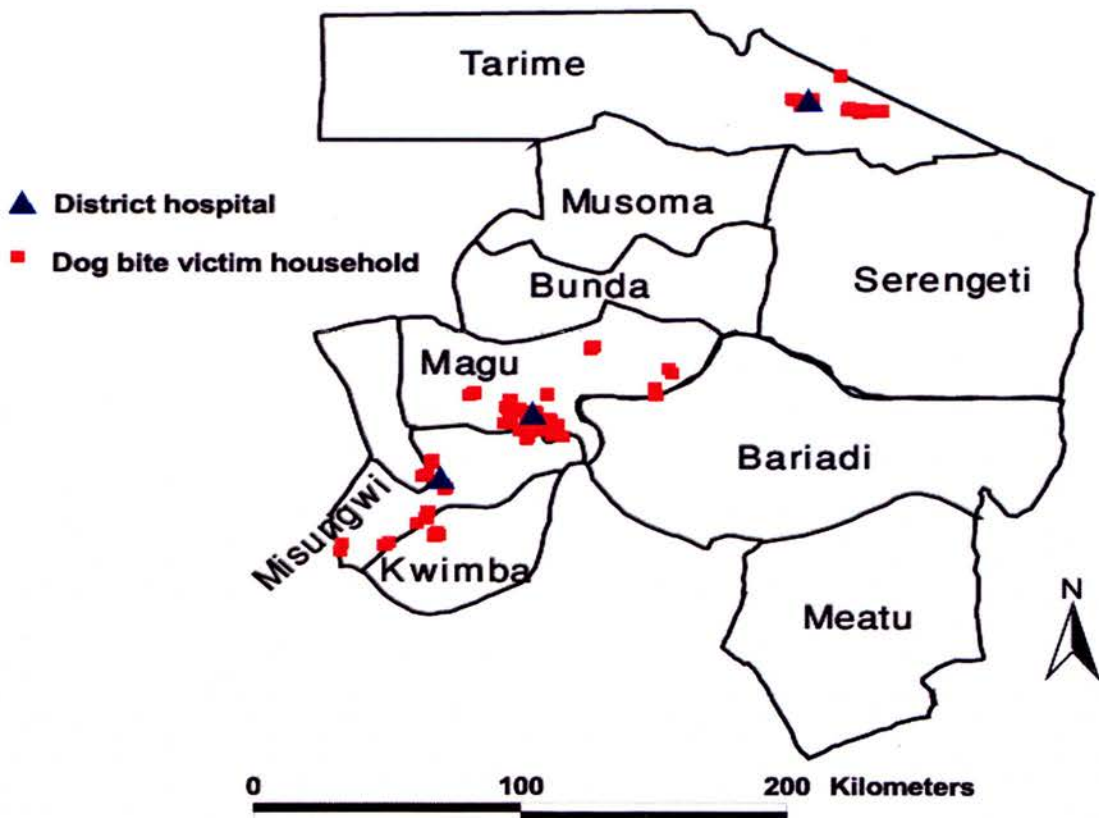
The aim of this study were therefore to evaluate and measure the economic burden of rabies for a rural Tanzanian community at household level focusing specifically on the costs of the disease for households, including both direct and indirect costs, some of household responses to these disease costs and the likely impact of rabies costs on household livelihoods.

3.1. Materials and method

3.1.2. Study area

The study was conducted in north-west Tanzania and included three districts namely Misungwi, Tarime and Magu in the Mwanza, Mara and Shinyanga respectively (Fig 3.1). The districts were randomly selected from a total of 24 districts in the area. Data for this study was gathered from a dog bite victims trace back questionnaire survey.

Figure 3. 1 : Map of study districts showing location of district hospitals and dog bite victims' Households



3.1.3. Identification of dog bite victims

Rabies is a notifiable disease in Tanzania and it is a mandatory requirement for hospitals to keep and maintain records and reports of human bite cases from suspected rabid dogs. Dog-bite victims were identified from animal bite hospital data recorded at district hospitals and reported monthly to central health authorities. All villages from where victims originated were listed and stratified into two categories based on the relative distance from nearest district hospital. Within 10 km individuals do not commonly pay for public transport and often either walk on foot or use own bicycles to travel to the nearest district hospital. Villages located within 10 km from the nearest district hospital were therefore categorized as near and those further than 10 km were classified as far. Four villages were randomly selected from each district: two “near” villages and two “far” villages. All reported dog bite victims were visited in their households and interviewed. In order to avoid missing dog bite victims who for any reasons might not have reported to one of the district hospitals, an inquiry was made at the village by asking village leaders and local dispensary staff if they knew of any person in a village who has been bitten by a dog within the last five years.

3.1.4. Household questionnaire survey

For the purpose of this study a household was defined as a group of people (or an individual) who share regularly the common means of livelihood and typically includes sharing meals. A structured open-ended questionnaire survey was administered to obtain information on rabies PEP expenditure (Appendix III). Where

possible information was collected from the actual bite victim. However, where the bite victim could not be interviewed either because the victim was a child or has little knowledge about variables under investigation (eg household expenditure) the head of household or another adult household member was interviewed. Because of the limitations of income as a measure of household well-being, household living standards were measured using information on monthly consumption expenditures, collected in the dog bite trace back questionnaire survey. Consumption, rather than income is preferable in measuring living standards for three reasons: i) it is difficult to measure the income of those working in the informal sector and self-employed individuals, and those who receive in-kind payments such as food or housing ii) survey respondents are likely to regard questions about consumption as less sensitive than questions about income and thus responses are likely to be more accurate iii) consumption is considered to more accurately represent long-term living standards because income may fluctuate over short periods (Johnson *et al.*, 2005).

Household expenditures were calculated from specific questions on household consumption expenditure per month on various food, non-food and durable goods for each household. In order to measure the financial costs due to rabies, respondents were asked how much they paid for rabies PEP which included expenditures on hospital registration, anti-rabies vaccine, admission where applicable, transportation and accommodation for the victims and accompanying adults where bite victims were children. In order to validate PEP costs incurred, heads of households were asked to produce receipts for medical costs. For estimation of productivity loss due to time lost while seeking PEP, respondents were asked to mention how much time

was spent by both the patient and carer in seeking the PEP. The time lost was used to determine the PEP opportunity cost for rabies and a person minding a victim from suspected rabid bite

In order to value in monetary terms the productivity loss while seeking PEP the time of household members was differentiated according to age and categorized into those less than or equal to 14 years, who are considered not to have started earning income, and those above 14 years who are considered to have started earning income through hiring out labour or involved in trading. The Tanzania *per capita* Gross National Income (GNI) (Ministry of Finance, 2004) was used to value the productivity loss.

In order to further explore the household burden of rabies, information was also collected on the number of health facilities visited by dog-bite victims for treatment including number of days spent at each health facility and amount of money paid for treatment, travel and boarding. Information was also collected about how households raised funds to pay for PEP cost.

Household socio-economic status was evaluated by collecting information on the number of livestock owned by a household, the quality of house and number and type of agricultural implements owned. In order to assess the concern of households about dog bites, respondents were asked to describe the relative concerns between a bite of suspected rabid dog in comparison to falling sick with malaria. Malaria and not other disease were chosen because the disease is known to be the leading cause

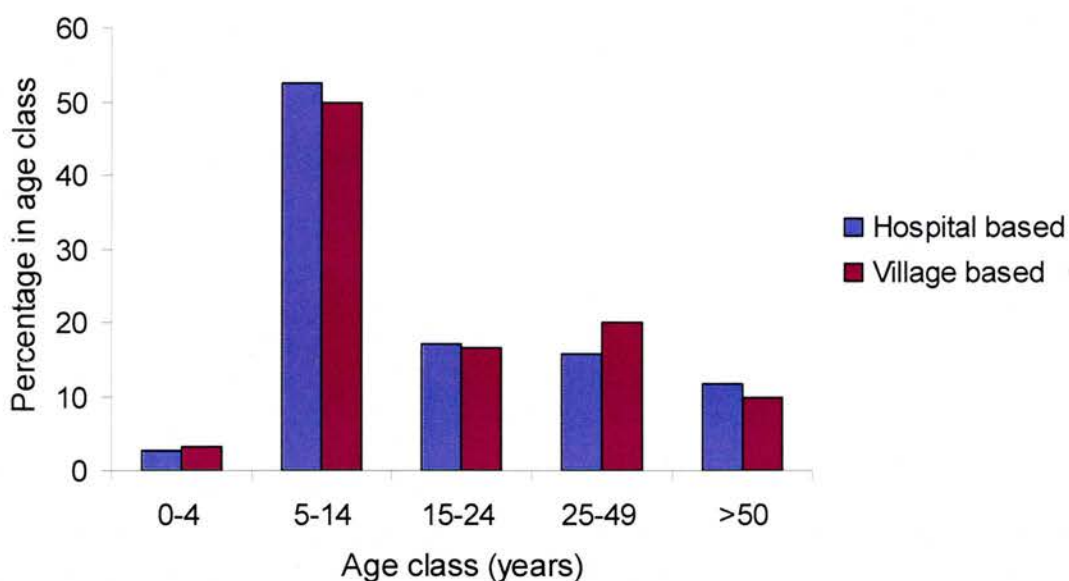
of mortality in most developing countries including Tanzania (World Health Organization, 2005).

3.2. Results

3.2.2. Age specific dog bite injury data

Using trace back data which recorded 182 dog bite victims, the distribution of dog bite victims demonstrated a significantly higher proportion of bite victims in individuals aged between 5 and 15 years old (Figure 3.2). Bite victims in this age class formed 54.5% (47-61.7) of all dog bite victims traced back. There was no significant difference in the age distribution of bite victims traced from hospital records and those obtained from village reports ($p= 0.921$, Fisher's Exact test).

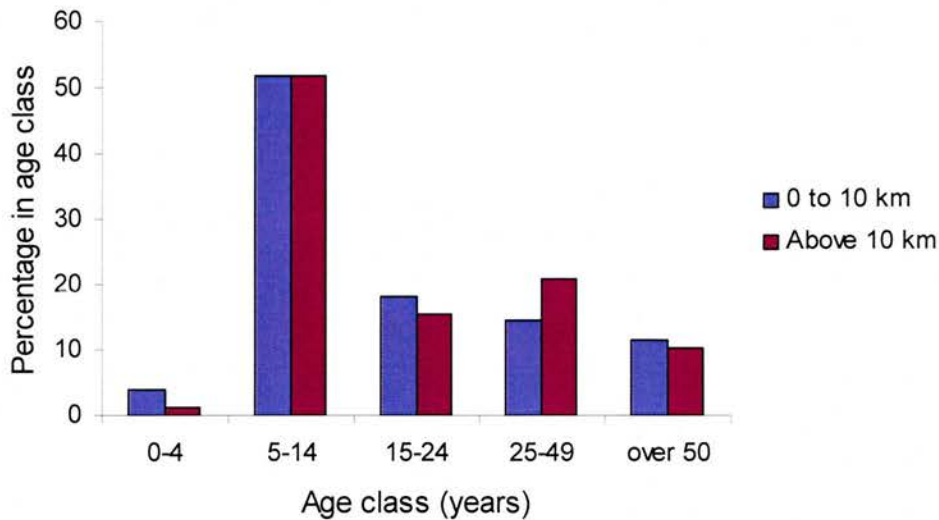
Figure 3. 2: Age distribution of dog-bite victims traced from hospital records and village reports.



There was no significant difference ($p=0.71$, Fisher's Exact Test) in the distribution of age specific dog bite victims between villages located near and far from the nearest government district hospital (Figure 3.3). In all cases, anti rabies vaccines

(ARV) for PEP were available and prescribed only at the district government hospitals. The PEP was administered according to the regime approved by Tanzanian health authorities which was 3 doses of ARV administered on day 0, 7 and 28. There was no rabies immunoglobulin available for administration to category III exposures. Out of all dog bite victims to whom PEP was prescribed, 5.4% (1.7-12.1%) received only two doses of ARV and cited shortage of funds as the reason for failure to complete the prescribed PEP full course of three injections and 1% (0.02-5.8%) received one injection of ARV and discontinued treatment after dogs were considered not rabid. Out of all bite victims traced, none died of rabies.

Figure 3. 3: Age specific distribution of dog bite victims in relation to location relative to nearby district hospital.



3.2.3. Treatment-seeking pattern

Figure 3.4 details the time interval taken by bite victims from being bitten by a suspected rabid dog to reporting to a nearest district hospital for treatment. Victims

located near district hospitals reported significantly earlier than those located far from district hospitals ($p < 0.0001$, Fisher's Exact Test) with 85.7% (95% CI 77.2 to 92) of victims near district hospitals reporting within 7 days from date of bite compared to 66.2% (95% CI 53.7 to 77.2) for victims located far from district hospitals. Interval to reporting in relation to socio-economic status is illustrated in Figure 3.5 reflecting significantly earlier reporting for bite victims with high socio-economic status than those with low socio-economic status (Socio-economic categorization defined in Chapter II) ($F_{1,175} = 51.7$, $p < 0.0001$). All bite victims (100%) with high socio-economic status reported to a district hospital within three days after a bite from suspected rabid dog compared with 30.4% (95% CI 22-39.7) for victims with low socio-economic status. None of the victims with low socio-economic status reported on day 0 compared with 30.9% (20.2-43.2) of bite victims with high socio-economic status.

Trace-back data showed that overall 2% (95% CI 0.65-6.01) of bite victims made a first consultation with traditional healers, 10% (95% CI 6-16) with the nearest public or private dispensary and 88% (95% CI 81.4-92.04) from the nearest district hospital (Fig 3.6). Analysis of the data found no significant difference between the number of bite victims reporting to district hospitals from villages located near to the hospital on first consultation, compared to those from "far" villages ($P = 0.2$, Fisher's Exact Test).

Figure 3. 4: Interval from dog bite to reporting to a health facility for bite victims in relation to location from district government hospital

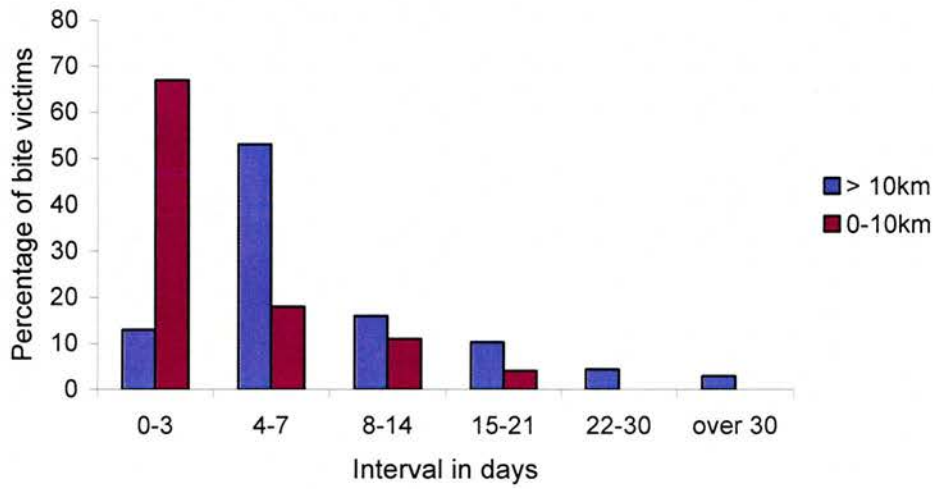


Figure 3. 5: Interval from dog bite to reporting to a health facility for bite victims in relation to socio economic status

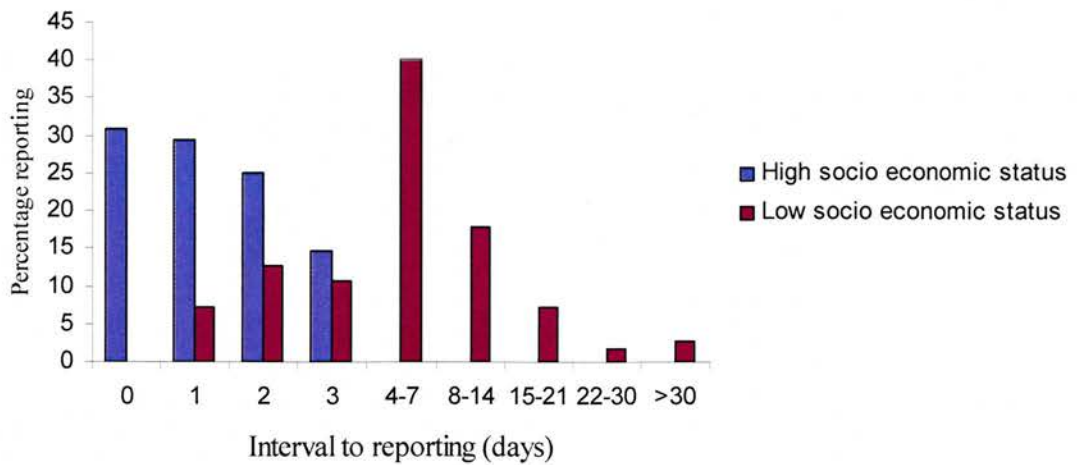
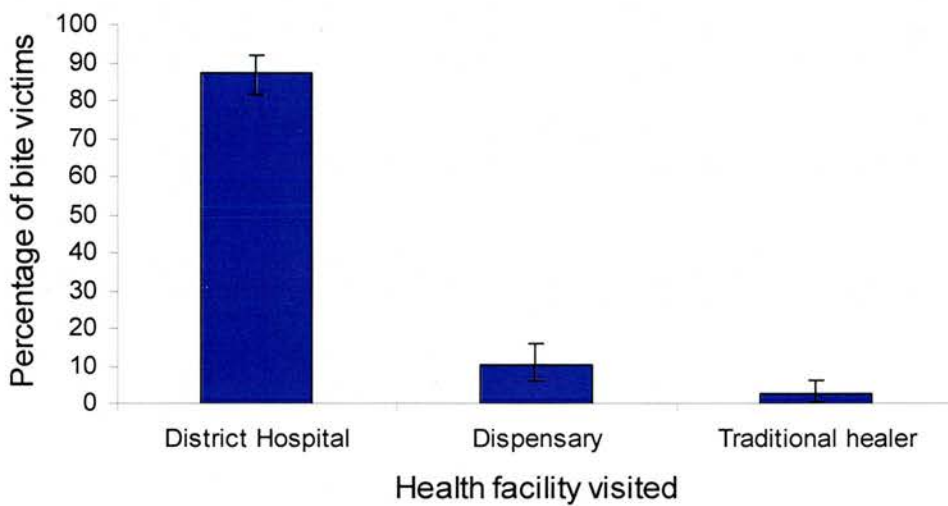


Figure 3. 6: Proportion of bite victims who attend to various health facilities for first consultation in the study area



3.2.4. Household PEP expenditure

Of all the dog bite victims traced, 53% (45.5-60.7) were treated by medical authorities as cases of bites from suspected rabid dogs and hence received PEP. The remaining proportion was treated as bites from non rabid-dogs and thus received only wound treatment. The average cost incurred for anti rabies vaccine was \$35.7 (95% CI 30.2- 41.2) per full course of PEP per patient, as per the Tanzanian schedule of three intramuscular injections administered on days 0, 7 and 28. Households also spent an average of \$1.23 (95%CI 0.71 – 1.76) for wound treatment and antibiotics and \$0.17 (95% CI 0.14 – 0.2) for hospital registration per bite victim. For medical costs therefore, on average a single household spent a total of \$ 37.1 for PEP direct medical costs alone per patient. The average household monthly expenditure for household with high socio-economic status was US \$ 74 (95% CI 70.3-78.5) and for households with low socio economic status was US \$ 35.5 (95% CI 33.6-37.1). The

per capita monthly expenditure for households with high socio-economic status was US \$ 12.3 (95% CI 10.8-15.7) and for household with low socio-economic status was US \$ 4.8 (95% CI 4.2-5.8). Household with low socio-economic status spent over 100% of their monthly consumption expenditures on PEP while those from high socio-economic status spent only 50% of their monthly consumption expenditures.

3.2.5. Transport and boarding costs while seeking PEP

On average households spent \$ 2.88 (95% CI 2.3- 3.7) for transport costs per person while seeking PEP, but only rural households located >10km from district hospitals sustained transport costs. Urban households and rural household located within 10 km from district hospitals either walked or used own and borrowed bicycles to get to health facilities. On average households spent \$14.8 (95% CI 10-19.6) as boarding cost for the entire PEP course per person. This expenditure did not apply to households located near to district hospital.

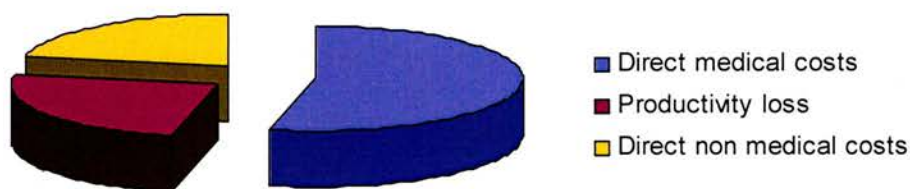
3.2.6. Productivity loss while seeking PEP

On average each household spent 6.4 days (95% CI 4.5- 8.3) for PEP. Bite victims from households located near district hospitals spent on average 5.8 days (95% CI 3.1-8.5) compared to 7.4 days (95% 5.0- 9.8) spent by bite victims from households located far from district hospitals. Bite victims less than 18 years old were accompanied by an adult person in all days of PEP treatment whereas adult bite victims (over 18 years) were accompanied by an adult person for at least one day of

PEP treatment. The monetary value for time lost was equivalent to \$17.3 per household per dog bite incident.

With all costs combined, a single household will spend a total of \$69.3 per dog bite from a suspected rabid dog. The relative contribution of the various categories of expenses for PEP is shown in Figure 3.7.

Figure 3. 7: Relative household costs associated with PEP for humans bitten by suspected rabid dogs.

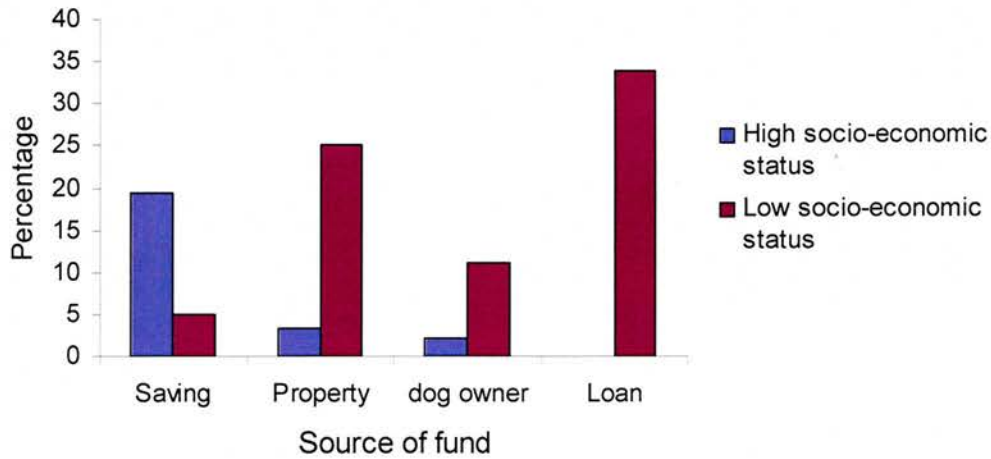


3.2.7. Raising funds for PEP

Four major means of raising funds for PEP were described which included i) family savings ii) borrowing money iii) selling of household properties and iv) the owner of dog that caused the bite paying for PEP. Socio-economic status had a significant impact on the source from which households obtained funds for PEP ($p < 0.0001$, Fisher's exact test). Higher income households were more likely to use savings, whereas households with low socio-economic status either obtained loans from

relatives, friends and neighbours or depended on owner of dogs which inflicted the bites to pay for PEP.

Figure 3. 8: Source of funds for PEP in relation to household socio-economic status estimated from household questionnaire survey



3.2.8. Community concern for dog bite

Out of the 182 households with dog bite victims interviewed, 87.7% were more concerned about bite from a suspected rabid dog than falling sick with malaria. The major reasons described for this concern were the treatment futility once a victim develops clinical rabies in comparison to malaria which can be treated, the difficulty in obtaining anti-rabies vaccine together with the relative high cost when available and need to travel long distances. For malaria on the other hand, individuals interviewed indicated that it is a common disease with effective drugs available locally and at a reasonably affordable price.

3.3. Discussion

The recent past has seen increased focus and effort by the international community to improve the health of the world's poor community. Attention has been focused on the relationship between health and poverty particularly in relation to the Millennium Development Goals (MDGs). One of the major goals of the MDGs is a reduction of number of the world population living in absolute poverty by 50% by 2015. Diseases such as malaria, HIV/AIDS and TB have featured prominently in terms of attracting funding, being given high priority by International Health Community and donor agencies. Conspicuously absent from these efforts by the International community is the commensurate advocacy of the zoonotic diseases of the developing world that affect the poor, marginalized and powerless communities particularly those in rural areas. The control of rabies, an important viral zoonosis, is still not perceived as a priority by the health systems of most developing countries as well as by the international community.

This study, however, demonstrates that bites inflicted to humans by suspected rabid dogs impose a substantial burden to households with costs for rabies PEP well beyond the majority of household monthly expenditures. In addition the spending pattern on PEP reveals the importance of non-medical costs, such as transport and boarding that are incurred by bite victims and their care givers. Because of the difficulty and centralized availability of PEP, a large proportion of dog bite victims in rural areas are compelled to travel long distances to health facilities at district headquarters, the only place where PEP is officially available and prescribed. Most

of the victims are normally accompanied by caregivers, a factor which imposes an additional cost burden to households.

Studies on economic burden of diseases such as malaria at household level have reported that generally households with low socio-economic status are likely to spend less on treatment than households with high socio-economic status. This is because households with low socio-economic status are likely to have difficulties in accessing medical facilities and unable to afford treatment costs. Findings of this study however indicate no difference in household spending for rabies PEP with households spending equally on PEP regardless of their socio-economic status. This highlights a high knowledge of the need for PEP within the community and indiscriminate household economic impact of rabies across socio-economic status with a disproportionately heavier economic burden for households with low socio-economic status. While households with high socio-economic status spend 50% of their monthly household expenditure on rabies PEP, households with low socio-economic status spend over 100% of their monthly household expenditure on rabies PEP. In both scenarios financing PEP represents a substantial drain to household monthly expenditures. However, the disproportionately higher burden of rabies on households with low socio-economic status, which are already on their marginal existence, is likely to have a significant impact on their livelihoods particularly in their ability to meet daily household subsistence needs.

Unlike other diseases such as TB, malaria and HIV/AIDS, a significantly higher proportion of individuals bitten by suspect rabid dogs seek first treatment from a proper medical facility where PEP is ideally supposed to be available. The use of

traditional health care was demonstrated to be very low in this study highlighting the high knowledge within the community about the proper medical care needed when an individual is bitten by a suspected rabid dog. In other diseases such as malaria, TB and HIV/AIDS the use traditional health services has been more widely reported, this is possibly due to chronic nature of the diseases which might be accompanied by unclear clinical signs to the patients. On the other hand people will immediately recognize the risk of bite by a suspected rabid dog and associate it with death if not properly treated at a hospital.

Households with members that incur dog bite are likely to face unexpected and immediate demand for cash. PEP cost absorbs a large proportion and thus the mobilisation of substantial additional resources. This study indicates that a significantly higher proportion of household with low socio-economic status were unable to promptly obtain funds for rabies PEP. Such households raised funds through various means including securing loans, selling and mortgaging household properties and waiting for owners of dogs which inflicted bites to pay for PEP. These coping strategies are likely to pose a significant difficulty for most household livelihoods particularly the vulnerable households with fewer assets.

The first seven days after a bite from a suspected rabid dog are critical for PEP (World Health Organization, 2004). However, bite victims from households with low socio-economic status were likely to report later for PEP, with none reporting on day "0" and only 30.4% able to report within day "3" of a bite. In comparison, 100% of victims from households with high socio-economic status had reported by day 3.

These findings indicate that dog bite victims from households with low socio-economic status are likely to be at higher risk of rabies death associated with this delayed reporting.

Another burden associated with rabies PEP that is likely to be under-estimated is the productivity loss due to time off work for both bite victims and accompanied person while seeking PEP at distantly- located district hospitals. This study has reported that on average a household with a dog bite victim lost six economically active person days per bite episode from a suspected rabid dog. Productivity loss alone accounted for up to 24% of the total costs associated with PEP. Although productivity loss due to work time lost may not be viewed as direct expenditure by some rural communities, its monetary value represents a substantial economic loss to dog bite victim's households.

The findings of this study suggests the need to improve PEP availability in Tanzania so that it is made available to most rural populations which suffer disproportionately higher economically in terms of PEP compared to the urban population. This will involve decentralization of the current PEP and make it available in village health centres which are in vicinity and more readily reachable by the rural population. With the existing well established cold chain under the EPI system in rural Tanzania with cold chain facilities available up to a village level under the donor and Government funded EPI, the decentralization of rabies PEP is likely to be realized without many difficulties across much of rural Tanzania.

**Chapter IV: Domestic dog vaccination costs and benefits of rabies mass
vaccination of domestic dogs in rural Tanzania**

4.0. Introduction

One of the major factors that hinders rabies control in the developing world is lack of adequate and precise data for the disease on the *per capita* cost for dog vaccination, cost effectiveness of various control strategies, the number of human rabies cases that would be avoided and the economic benefits that would result from rabies control (Coleman *et al.*, 2004; World Health Organization, 2004). As a result the feasibility and sustainability of rabies control programmes has not been clearly understood by both local and international policy makers. In developing countries where resources and health budgets are limited the disease is not being accorded adequate control priority in comparison with other disease. The health budgets in most developing countries are likely to be over-stretched for some considerable time. At the same time, domestic dog mass vaccination programmes become more expensive particularly in parts of rural Africa where the dog population is growing disproportionately faster than human populations (Kitala *et al.*, 2001; Cleaveland, 1996). The likely future increase in rabies vaccination programme costs together with burden of controlling diseases in general, are likely to require objective and informed decisions about the costs and economic value of controlling rabies in comparison with other competing public health priorities. Health policy-makers need information about costs and economic values of disease control programmes to ensure that healthcare resources are used efficiently. Economic and logistical factors have been identified as some of the major constraints to effective dog rabies control in eastern and southern Africa (Perry, 1993).

Canine rabies is endemic in most of the developing world where it causes a substantial public health and economic burden to Governments and communities (World Health Organization, 2001; Knobel *et al.*, 2005). A recent study estimated that up to 55,000 people die annually due to rabies in Asia and Africa (Knobel *et al.*, 2005). The World Health Organization estimates that up to 10 million people receive the expensive PEP (World Health Organization, 2001; Knobel *et al.*, 2005).

Due to the high incidence of rabies in Africa and Asia, the demand for PEP in these region is likely to be high with costs related to PEP estimated to account for up to 5.8% and 3.9% of the *per capita* gross national income in Africa and Asia respectively (Knobel *et al.*, 2005) which is a substantial economic burden to the public health sector and a considerable drain to the overall national budgets of these governments which are already financially constrained. In terms of livestock, household losses up to \$ 7.5 per year have been reported in Ethiopia (Laurenson *et al.*, 1997), a substantial loss in a country where many households earn less than \$1 a day. In addition rabies impinges greatly on individual household economies, particularly in rural Africa, where families are likely to spend a substantial amount of their income for rabies PEP and treatment-seeking beside the intangible burden of the disease such as the psychological trauma and agony for fear of rabies which most families go through (Knobel *et al.*, 2005, Chapter III). Rabies in wildlife has contributed to the local extinction of wild dogs in the Serengeti where the wild dog population is reported to have declined from 110 in 1966 to complete disappearance in 1993 following successive outbreaks of rabies (Gascoyne *et al.*, 1993a; Gascoyne

et al., 1993b; Woodroffe *et al.*, 2004). The available evidence in Serengeti suggests a pattern of spill-over of rabies infection from domestic dogs to wildlife, a finding which indicates that eliminating rabies in domestic dogs is likely to result in elimination of the disease in wildlife (Cleaveland & Dye, 1995; Lembo *et al.*, 2006 unpublished). The disappearance of wild dogs from the Serengeti is not only a concern for the conservation of the species which is highly endangered but may have implications for park revenue generated from game-viewing tourists. Wild dogs have been reported to be one of the major attractions to tourists visiting South Africa National Parks (Lindsey *et al.*, 2005). The multi-host nature of the rabies virus therefore makes the disease an important multi-sectoral problem.

Rabies control strategies have traditionally involved mass vaccination of domestic dogs and culling of “stray” and ownerless dogs. However in recent years culling is being increasingly discouraged because of its ineffectiveness in controlling both rabies and dog populations and concerns about animal welfare (Bogel & Meslin, 1990; World Health Organization, 2004). Mass vaccination therefore remains the major recommended approach to controlling rabies in the animal species identified to be the principal reservoir hosts (World Health Organization, 2004). Although mass vaccination programmes have succeeded in freeing the majority of Western Europe and North America from rabies, it has been unable to contain the disease in most of the developing World, where dog rabies is still endemic and the incidence is considered to be rising (Cleaveland, 1998; Perry, 1993; Parviz *et al.*, 2004). Failures of mass vaccination campaigns to control dog rabies in the developing countries have been attributed to a variety of factors, including failure to take cognisance of the host

population biology in the design of vaccination programme, lack of political will among developing country governments, competing national health priorities and inadequate resources to finance vaccination programmes.

For rabies control, various disease control strategies have been applied in different settings with varying degrees of efficiency. In Kenya for example, a comparison of door-to-door and central-point rabies vaccine delivery approaches in low-density dog populations among the Maasai ethnic group showed that the door-to-door strategy was more efficient than central-point in terms of vaccination coverage and average time used to vaccinate a single dog (Coleman, 1999). On the other hand, studies in Kenya and Tanzania which involved rural dog populations of comparatively higher densities than the Maasai showed that sufficient vaccination coverage can be achieved through simple centralized vaccination programmes (Kitala *et al.*, 2002; Cleaveland *et al.*, 2003; Perry *et al.*, 1995). All of these studies were carried out in East Africa but none have attempted to quantify the costs and benefits associated with the various rabies control strategies in question.

There are only few published studies which have attempted to assess *per capita* costs of dog vaccination and the benefits of rabies control. Based on an interview survey of veterinary practitioners in the Republic of Philippines, a range of US \$ 1.19 to 4.27 has been estimated as the cost of vaccinating a dog (Fishbein *et al.*, 1991). In Tunisia and Thailand, the cost of dog vaccination has been estimated to range from US \$ 0.52 to 0.95 per dog vaccinated (Bogel & Meslin, 1990). The authors did not explicitly describe which approach of vaccine delivery was used to estimate the *per*

capita cost of dog vaccination. A recent study in Chad estimated central point dog vaccination *per capita* cost of urban dog at € 1.93 (Kayali *et al.*, 2006). However, the existing knowledge base on the economics of rabies control, such as the *per capita* cost of dog vaccination and benefits of rabies control programme, is still scarce and limited only to a few studies that are hard to compare, generalize, or relate to the practical field situations. In the absence of robust economic and public health information, particularly on the benefits and costs associated with the available rabies control strategies, it becomes difficult to allocate resources efficiently and decide which strategy to adopt. In this chapter, data are presented that will provide policy makers with information on *per capita* cost for parenteral dog vaccination in north-western Tanzania which is likely to be relevant for most rural settings in Tanzania and Africa.

Economic evaluations are widely used to assess the efficiency of public health interventions, but have been used less often in veterinary disease control programmes. In human diseases, the techniques have provided an important base for choice of economically effective disease control strategies. In malaria control for example, studies of the cost effectiveness of various control approaches such as insecticide treated nets (ITN), in house residual spraying (IRS), pregnancy intermittent treatment and improved malaria treatment (Bhatia *et al.*, 2004; Goodman *et al.*, 1999), have been used to prioritize control strategies with ITN shown to be more cost-effective than other strategies.

Another crucial aspect of mass vaccination against rabies is the effectiveness of the programme as measured by the coverage achieved. To qualify as epidemiologically worthwhile, a vaccine delivery strategy needs to be effective in both unit costs and coverage. Theoretical epidemiology predicts coverage of 70% as the pre-requisite for prevention of epidemics (Coleman & Dye, 1996). The major problem for most of the implemented mass vaccination programmes has been the failure to achieve the recommended 70% coverage. This is particularly so in remote pastoral communities like the Maasai in northeast Tanzania and Masai Mara in Kenya where central point coverage as low as 4- 6% has been reported (Cleaveland, 1996; Coleman, 1999). In communities like these it may be important to develop innovative vaccine delivery strategies to achieve sufficient vaccination coverage and investigate the dog vaccination *per capita* cost for these strategies.

The current trend for most African government veterinary services is to decentralise clinical and preventative animal health care to the private sector. The rationale for this approach derives from the first theorem of welfare economics which assumes that in the absence of externalities, public goods, information failures or economies of scale, private markets are the most efficient way of service delivery (Stiglitz, 2000). Privatization of veterinary services in Sub-Saharan Africa is considered one of the major reasons for the weakened delivery of veterinary services in the region (Rweyemamu *et al.*, 2006). Changes in the approach for delivery of animal health services are considered not to have sufficiently considered the delivery of public goods such as the control of zoonotic diseases (Rweyemamu *et al.*, 2006).

Given the inability of governments to deliver sustainable veterinary services to remote pastoral locations, the community-based animal health worker (CAHW) approach was initiated several years ago in various African countries in order to meet the needs of the livestock owners. A CAHW is a part-time animal health worker who, ideally, owns livestock and in the case of pastoral communities, is able to travel with herds to remote grazing areas. The CAHW aims to treat diseases which are prioritised by the community. Lessons from southern Sudan indicate that well-coordinated, large-scale community animal health worker (CAHW) systems can form the basis for improved and effective vaccine delivery strategies that compare favourably with and even surpass the vaccination efficiencies achieved by government veterinary services (Jones *et al.*, 1998). In Kenya, for example, smaller scale CAHW projects in semi-arid areas have demonstrated substantial cost-benefit through the prevention or treatment of important livestock diseases (Leyland *et al.*, 2005). In some areas, such as the Afar region of Ethiopia, CAHWs have played an essential role in rinderpest eradication, one of most economically important livestock diseases (Catley *et al.*, 1998). To varying degrees, all these areas were characterised by limited government veterinary services, logistical problems, and poor infrastructure, constraints that are also highly relevant to the current situation in Tanzanian pastoral communities. The effectiveness of CAHWs in these areas demonstrates their potential as alternative service models for the veterinary sector where conventional models cannot cope with the scale of the need.

This chapter estimates the *per capita* cost of dog vaccination in agro-pastoral and pastoral communities in rural Tanzania and compares, from the animal-health

services provider perspective, the *per capita* cost of dog vaccination by central point parenteral rabies vaccination strategy in the agro pastoral and pastoral community in north-west Tanzania. The study also explores alternative strategies for parenteral vaccine delivery in domestic dogs among remote pastoral Maasai communities in Tanzania and goes further to compare the dog vaccination *per capita cost* for these strategies. Three rabies vaccine delivery strategies namely parenteral central point, combined central point and parenteral house-to-house and combined central point and use of community based animal/health workers are investigated. The study also estimates prospectively the benefits that could accrue to the public health sector from rabies control by mass vaccination of domestic dogs.

4.1. Materials and methods

4.1.2. Study area

The study area was divided into two zones in north-western Tanzania based on their location relative to Serengeti National Park (Chapter II). The eastern part of the park was categorized as the pastoral zone and comprised the Ngorongoro district. In this district, the study confined itself to the Loliondo Game Controlled Area (LGCA) which is inhabited predominantly by pastoral Maasai and Sonjo communities. The western part of the park was categorized as the agro-pastoral zone and comprised six districts namely Serengeti, Tarime, Bunda, Magu, Bariadi and Meatu. Communities in the western part of the park are multi-ethnic and practice agricultural and livestock production. In the western part, the study included all villages which lie within 10 km of the border of the Serengeti National Park and/ or surrounding game reserves while in the eastern part the study included all the villages within the Loliondo Game Controlled Area.

4.1.3. Vaccination strategies in the agro pastoral communities

Full details on the implementation of the vaccination campaign are provided in Chapter II. In the agro-pastoral communities to the west of the Park a central point vaccination strategy was adopted. The date of the vaccination was communicated to dog owners at least one week before through official letters to village authorities which included village and sub-village chairpersons. One day before the vaccination a reminder was sent to the villagers using an advertising team which delivered the

information to schools and village leaders. Dog owners were asked to bring all dogs to a centrally-located point in a village for vaccination. In the advertisements dog owners were informed that the vaccination was provided free of charge.

On the vaccination day a team of four people was stationed at the central vaccination point from 9.00am in the morning. Each member in the team was assigned a specific task. The tasks included dog registration, certificate writing, and vaccine administration by injection and fitting plastic collars on vaccinated dogs. Dogs brought to the vaccination point were sub-cutaneously injected with an inactivated rabies vaccine (Novibac Rabies[®] Intervet,) and DHP vaccine (Novibac DHP[®] Intervet), although only costs for the rabies vaccine were included in this analysis. Disposable needles and syringes were used. Needles were used only once for each dog while syringes were recycled for every 20 dogs. The team remained at the vaccination point until no more dogs were forthcoming for half an hour.

4.1.4. Vaccination strategies in the pastoral communities

Two combined approaches that allowed assessment of three vaccine delivery strategies were evaluated. The approaches were a) central-point and house-to-house and b) central-point and use of community animal health workers (CAHW). The two approaches were identified and agreed upon in a participatory manner following a discussion involving stakeholders and district and village levels, including district and mission hospitals, village primary health-care workers, village community-based

animal health workers and district veterinary officers. This combination of two strategies allowed investigation of three vaccine delivery strategies namely:

(a) Central-point strategy (CP), where information about the vaccination was conveyed through letters sent to village authorities a week prior to the vaccination day. A reminder was sent a day before the vaccination. The advertisement approach and message content was the same as for the agro-pastoral zone and people were asked to bring their dogs to a central location within a village where a team of three people comprising of staff from the district veterinary office (livestock field officers) carried out the vaccination work. The vaccination team tasks included dog registration, certificate writing and vaccination of dogs, each task carried out by a different person.

(b) Combined central-point and house-to-house (CP-HH), where a team of two persons visited each selected village after the central point vaccination; the vaccination team systematically visited each household in a village and, where dogs had not been vaccinated by the central point approach, carried out the vaccination, dog registration and issuing vaccination certificates at the household.

(c) Combined central-point and community-based strategies (CP-CAHW), where village animal-health or primary health workers received training to vaccinate dogs, were provided with vaccine, consumables, bicycles to access cold-chain facilities, and assigned the duty of vaccinating dogs that were not vaccinated in the central-point approach. CAHWs were left to carry out the vaccination using their method of choice over a time frame of three months.

4.1.5. Costs of the domestic dog vaccination programme

The costs estimated in this study are summarized in Table 4.1 and 4.2. All costs were estimated in Tanzanian shillings (TZS) and then converted to US dollars (US \$) at an exchange rate of TZS 1,080/US \$ which was applicable in year 2004. The costs of each resource were based on actual expenditure at applicable market rates at the time when this study was undertaken.

For the agro-pastoral zone the cost was estimated from the entire vaccination zone which comprised 145 villages with 27,400 dogs vaccinated by central point vaccine delivery approach in the first vaccination campaign implemented in year 2003. For the LGCA the costs for the CP and combined CP-HH and CP-CAHW strategies were estimated from 21 villages within the LGCA, 910 dogs were vaccinated by central point vaccine delivery, 1530 dogs vaccinated by CP-HH combination and 2631 dogs vaccinated by CP-CAHW combination. The animal health provider perspective was used to conduct the cost analysis for the domestic dog vaccination whereby costs were estimated as being incurred by the veterinary sector alone. Vaccination costs were estimated by assigning a monetary value to supplies and consumables (vaccine, needles and syringes) based on the applicable market prices. *Per diem* and overnight allowances paid for the vaccination campaign were based on applicable government rates for livestock field officers. Capital costs were amortized based on 5% discount rate and five and ten year's life span for the capital equipments (vehicle and refrigerator respectively). Since capital equipments were not used solely for the rabies vaccination programme the annualized costs rather than total costs of capital

equipment was used in the cost analysis. The annualized cost was multiplied by the number of days the equipment was used for the vaccination campaign and then divided by the total number of days in one year. Costs related to cold chain, transportation, vehicle repairs, community mobilization and sensitisation, supervision and training of vaccinators were included in the costing.

To allow for uncertainty and variability of the cost, probability distributions were assigned to input variables. Normal probability distribution was assigned for variables in which means and confidence interval could be estimated and triangular probability distribution for variables which showed peaked distribution. The input variables were sampled iteratively 1000 times using a Monte Carlo simulation procedure (@Risk Pro 4.5, Palisade Corp., Newfield, New York). The cost per dog vaccinated was reported using the mean of the resulting probability distributions, with the 5th and 95th percentiles as the lower and upper limits respectively. Sensitivity analysis was carried out in @RISK by stepwise multivariate regression analysis to estimate the impact of cost variables on the effectiveness measure of cost per dog vaccinated. This allowed estimation of the most critical cost variables.

4.1.6. Incidence of human bites from suspected rabid dogs

It is widely recognised that rabies is a grossly under-reported disease with most cases of human bites from suspected rabid dogs not routinely reported to the government hospitals. In order to obtain more detailed and relatively accurate incidence data on human bites from suspected rabid dogs, data were collected from the household

questionnaire survey (Appendix II) for years 2004 and 2005 on the number of household members bitten by suspected rabid dogs within the agro-pastoral vaccination zone. Since it is less likely that all bite victims reported by households received PEP, and because rabies recognition probability within households is less likely to be 100% accurate, the study assumed that PEP was administered only to 70% of all bite victims reported by households. This is consistent with rabies recognition probability reported by Cleaveland *et al.*, (2003).

4.1.7. Estimation of cost due bites from suspected rabid dogs

Public medical costs were estimated by valuing the direct PEP medical costs incurred for bite victims. These included costs for human anti-rabies vaccine US \$ 10, the hospital administration cost including medical personnel's time, costs for wound treatment (antibiotics) US \$ 1.85 and tetanus toxoid US \$ 1.4. The administration cost was valued based on the registration and consultation fees paid by patients when they attend a government hospital which was equivalent to US \$ 3.7. These fees reflect the administrative cost per each patient attending a hospital. For the human rabies vaccine we adopted the official price charged by the Tanzania medical stores department which is \$10 per dose. For wound and antibiotic treatment we adopted the fee charged by government hospitals which is \$1 per wound treated. For PEP the study considered two scenarios: a) PEP according to Tanzania health authority regime whereby patients are given three doses of human anti-rabies vaccine (ARV) on days 0, 7 and 28 without Rabies Immunoglobulin (RIG) (This schedule is not in accordance with WHO recommendations and its effectiveness in preventing human

death from rabies is not known but is not considered sufficient to eliminate human death due to rabies) b) PEP according to the WHO recommended Essen regime involving administration of five doses of human anti-rabies vaccine on days 0,3,7,14, and 28 and 20IU/kg of human RIG per patient. The cost of human rabies immunoglobulin used in this study was US \$160 and was obtained from the United Nation Development Programme (UNDP) Inter-Agency Procurement Services Office (IAPSO) which is the sole WHO procurement services provider. All human bites from suspected rabid dogs reported from household questionnaire survey were category III exposures, human rabies immunoglobulin was therefore considered necessary for all bites recorded. In both scenarios compliance rate (which is the proportion of bite victims who received the full ARV as recommended by clinical officers) for PEP was considered to be 97% based on household questionnaire survey data and PEP hospital records observed in the present study. The WHO recommended Essen regime is considered as the optimal PEP approach for eliminating human death by due to rabies.

4.1.8. Estimation of direct non medical costs due to bites from suspected rabid dogs

The cost of household out- of- pocket expenditure for PEP was estimated through trace-back household questionnaires of dog bite victims who had reported to hospitals. Data were collected on the amount of money spent to cover travel, meals, accommodation and other incidental expenses associated with seeking treatment for injuries from suspected rabid dogs.

4.1.9. Estimation of indirect medical costs due to bites from suspected rabid dogs

Indirect medical costs were estimated from travel and boarding costs for bite victims and accompanying person and work loss due to rabies which was assumed to result from a) productivity loss suffered by dog bite victims constituting the labour force and b) the need of individuals constituting the labour force to accompany bitten children aged 0-15 years for PEP seeking. The Tanzania Integrated Labour Force Survey reported that the majority of the economically active population are in the age group 15 – 49 years (Tanzania National Bureau of Statistics, 2002). For economic analysis the present study considered the labour force to be constituted by individuals in the age group 15 to 49 years old. The productivity loss suffered by both the bite victim and accompanying person(s) was computed from the number of days spent in seeking PEP and the Tanzania *per capita* National Gross Income (Ministry of Finance, 2004). Time spent seeking PEP was obtained through the trace back household questionnaire surveys as described earlier.

4.1.10. Effectiveness measure

The study assessed two measures of effectiveness: cost per dog vaccinated and cost per Disability Adjusted Life Year (DALY) averted. The cost per dog vaccinated was derived from the total cost incurred for dog vaccination campaign divided by total number of dogs vaccinated. The cost per DALY averted was computed based on the total cost divided by total DALYs averted. We used DALY data estimated in previous studies in the same area (Cleaveland *et al.*, 2002). The number of human

bitten by suspected rabid dogs prevented were computed based on the difference between the number of human cases observed before and after the vaccination intervention using the number of human bites from suspected rabid dogs reported from the household questionnaire surveys for years 2004 and 2005 within the vaccination zone. Due to the problem of the under-reporting of the incidence of rabies, the human dog bite data collected in the household questionnaire survey are considered to realistically reflect the most likely human bite incidence from suspected rabid dogs.

4.1.11. Benefit estimation

The benefit estimation included the evaluation of the impact of rabies on public health whereby the study considered the benefits accruing from avoiding direct and indirect medical and non medical costs due to PEP. For the direct and indirect medical costs the study included costs due to PEP based on WHO recommended Essen schedule of five doses of ARV, wound treatment, administrative costs, antibiotics and tetanus toxoid. The cost for rabies immunoglobulin (RIG) was not considered in the evaluation. For direct and indirect non medical costs we considered patients' out-of-pocket expenses paid for items outside the health care sector. This included such costs as: (1) travel, meals and lodging for the patient to and from the health facility and (2) travel, meals and lodging for a companion. For the indirect costs we considered lost productivity from time off work due to rabies. Data collected from the household questionnaire surveys (Chapters II and III) in this study were used to parameterize a simple spreadsheet model to estimate the benefits of dog

vaccination from a dynamic perspective over a 15 years period. Costs and benefits were discounted to the net present value at 5%. In order to estimate the benefit of dog vaccination the sequence of domestic dog mass was assumed to proceed in the following phases: i) the first phase with a two years time-frame aimed at establishing and stabilizing recommended vaccination coverage levels for rabies control ii) a consolidation phase of four years to ensure coverage levels achieved in the first two years are maintained and all residual foci of rabies are eliminated iii) maintenance phase which will involve vaccination of small proportion of the dog population which is at high risk such as along the borders of the vaccination zone. The vaccination zone was considered to be a spherical zone with a total area of 6,922 km². The area of the vaccination zone was derived from total district area with all villages in the vaccination zone assumed to have an average rather than actual area size. The maintenance phase of the programme was considered to target 5% of the entire vaccination zone with efforts concentrated only along the borders of the vaccination zone. The model assumes a rabies recognition probability of 70% (Cleaveland *et al.*, 2002). Thus only 70% of all victims reported by households as cases of bites from suspected rabid dogs are assumed to qualify for PEP. Although Tanzania uses a truncated PEP schedule of three injection of anti-rabies vaccine (ARV) the WHO recommended Essen schedule of five injections of ARV vaccine was used in the model. This was done in order to give realistic estimates for the standard WHO recommended PEP schedule. The full cost of PEP estimated in this study (Chapter III) was used to parameterize the model. The spreadsheet model made the following important assumptions:

- Only 70% of the dog population is vaccinated

- Dog density of 5 dogs/ km² which allowed estimation of total dog population size in the vaccination zone
- Only 80% of human bite victims from suspected rabid dogs receive PEP and all victims who receive PEP do not die of rabies
- Out of bite victims who do not receive PEP only 20% die of rabies

4.2. Results

4.2.2. Vaccination cost per dog for parenteral central point strategy

The cost per dog vaccinated in pastoral communities, using the central point vaccination strategy, was \$5.5 (3.83-7.43) (Figure 4.1) whereas for agro-pastoral communities the cost per dog vaccinated was \$ 1.73 (0.84-2.69) (Figure 4.3). Sensitivity analysis of the variables illustrated that the number of dogs vaccinated had the biggest impact on cost per dog vaccinated in both agro-pastoral and pastoral communities. (0.99 for the agro pastoral zone and 0.57 for the pastoral zone). For the agro-pastoral zone all other variables had little impact on the total cost (the sensitivities were <0.01). In the pastoral zone the vehicle maintenance cost had a substantial impact on the cost per dog vaccinated (0.52 sensitivity). For other variables the sensitivity was <0.01 .

Figure 4. 1: Histogram demonstrating distribution of cost per dog for the central point vaccination strategy in the pastoral community

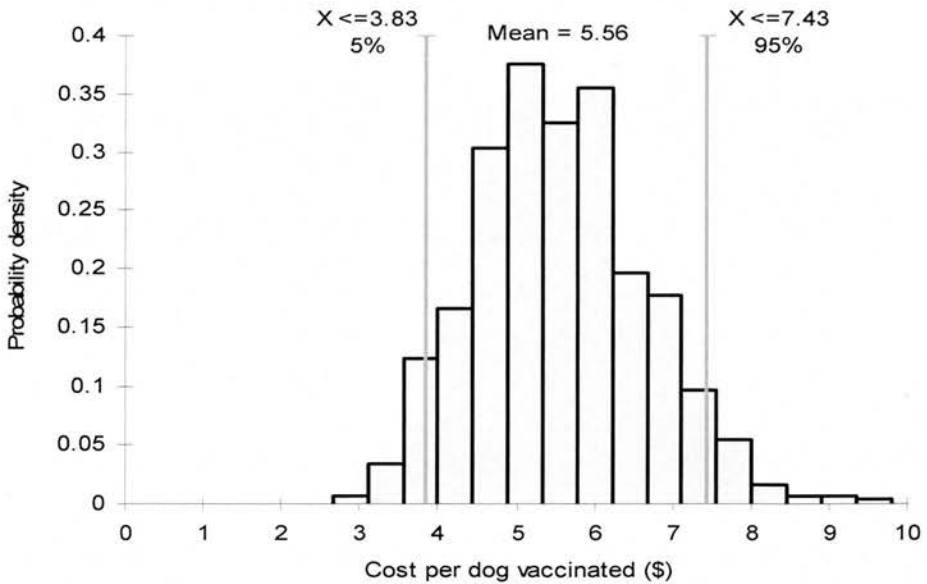
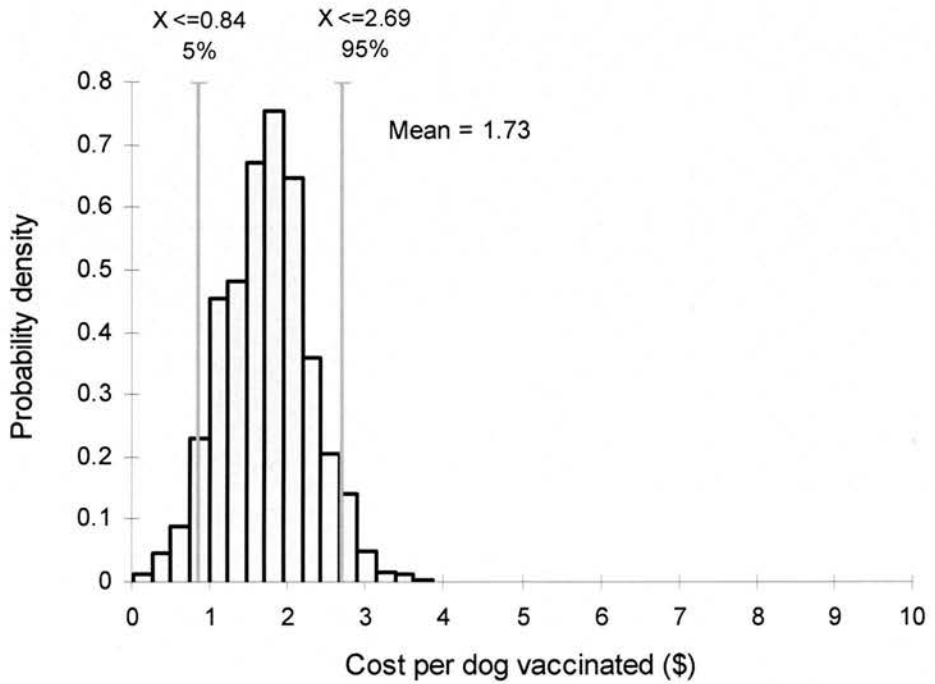


Figure 4. 2 Distribution of cost per dog for the central point strategy in the agro pastoral community



4.2.3. Dog vaccination costs for combined CP-CAHW and CP-HH strategies

The cost for the combined CP-CAHW and CP-HH are illustrated in Table 4.1 and Figures 4.3 and 4.4 respectively. The *per capita* cost of CP-CAHW was US \$ 4.07 (3.41 to 4.77) which was less than US \$ 6.13 (4.9 to 7.41) for the CP-HH strategy.

Figure 4. 3: Histogram illustrating the distribution of cost per dog for the combined CAHW and CP approach

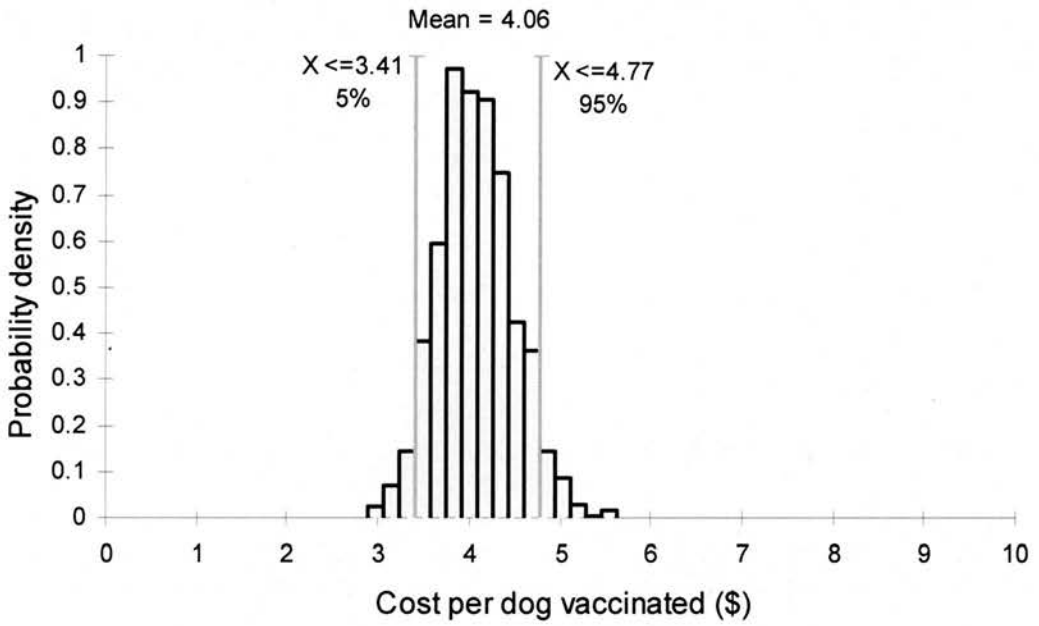


Figure 4. 4: Histogram illustrating distribution of costs for combined house- to-house and central-point approach in the pastoral community

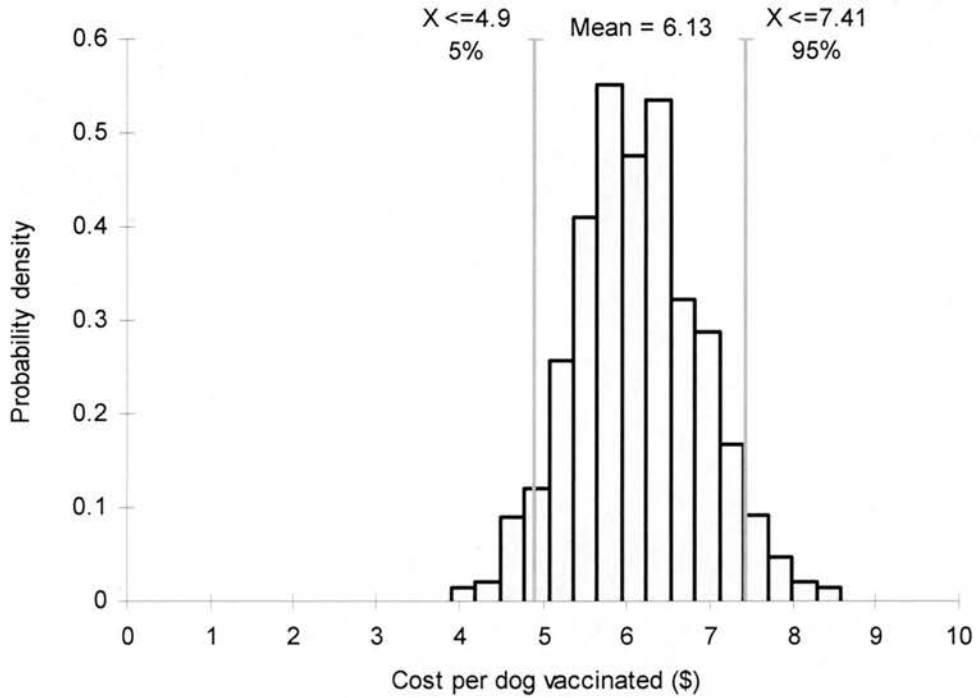


Table 4. 1. Coverage and per capita cost of dog vaccination of different strategies in pastoral zone.

Strategy	Vaccination coverage % (95% Confidence interval)	Cost per dog vaccinated(\$) (95% Confidence interval)
Central point(CP)	19.20 (11.4-27)	5.55(3.83 to 7.43)
Combined CP-HH	80.10 (75.0-85.2)	6.13(4.9 to 7.41)
Combined CP-CAHW	86.30 (81.8-90.7)	4.07 (3.41 to 4.77)

4.2.4. Total vaccination campaign cost

The total cost for conducting a central point mass vaccination campaign for the whole of the vaccination zone in the agro-pastoral area comprised of 145 villages was estimated to be US \$ 47,346 (Table 4.2). This was calculated from the realistic vaccination costs estimated from the year 2003 vaccination campaign which involved 14 villages within the vaccination zone and achieved an overall coverage of 80% coverage with 27,400 dogs vaccinated. The campaign lasted from June to October 2003 and involved two campaign teams with four people on each team. For the pastoral LGCA the total cost for central point vaccination campaign was US \$ 5,014 (Table 4.3). The vaccination programme in the LGCA was conducted from January to February 2004 and covered 21 villages with 910 dogs vaccinated.

Table 4. 2: Total cost of each item used for the central point vaccination campaign for the entire vaccination zone (Chapter II) in the agro-pastoral zone which covered 145 villages with 27,400 dogs vaccinated

Cost item	Amount (US \$) (95% CI)	Percentage of total cost
Vaccination disposables (syringes, needles, certificates, registers, collars)	2,694 (1872-3215)	5.69
Fuel	4,643 (3742-5430)	9.80
Allowance	7,036 (6,201-8,132)	14.86
Stationery	41 (32-48)	0.08
Vaccine	13,818 (12,120- 14,760)	29.18
Vehicle maintenance	10,443 (9,742-11,325)	41.72
Capital costs (Vehicle and fridge)	8,671 (7,432-9,623)	18.31
Total cost	47,346 (35,568-61,785)	
Cost per dog vaccinated	1.73 (0.84-2.69)	

Table 4. 3: Total cost of each item used for the central point vaccination campaign for the Loliondo Game Controlled Area in the pastoral zone which covered 21 villages with 910 dogs vaccinated

Cost item	Amount (US \$) (95% CI)	Percentage of total cost
Collars	35 (31-39)	1.00
Vaccination disposables	132 (112-148)	2.64
Fuel	926 (821-1002)	18.47
Allowance	1,049 (905- 1152)	20.94
Stationery	7 (3-12)	0.15
Vaccine	688 (521-802)	13.74
Cool boxes	83 (63-102)	1.66
Vehicle maintenance	2,092 (1889- 2201)	41.72
Total cost	5,014 (4886-5176)	
Cost per dog vaccinated	5.55 (3.83-7.43)	

4.2.5. Direct medical costs

Based on data from the household questionnaire survey the annual number of human bites from suspected rabid dogs reported for year 2004 in the entire vaccination zone was 481 cases per 100,000. After the vaccination programme intervention the number declined to 87 cases per 100,000 per year representing a 82% decline. The vaccination programme prevented 395 cases per 100,000 per year. The Tanzania Health authority prescribes a truncated PEP schedule of three doses of anti-rabies vaccine per person and no rabies immunoglobulin is used in this. The PEP cost that could be avoided by preventing human exposure through controlling the disease in domestic dogs for the first year of the dog vaccination programme amounts to \$ 67,76.84 per year based on the Tanzanian PEP regime (Table 4.4) and \$ 272,616.63 based on the WHO recommended PEP schedule which includes rabies immunoglobulin (RIG) (Table 4.5).

Table 4. 4: Cost for rabies PEP estimated from human dog bite cases reported from the household questionnaire survey and based on the Tanzanian health authority PEP schedule. The cost is based on the entire vaccination comprised of 145 villages with 466,989 humans.

Cost item	Amount (\$)(95% confidence interval (CI))	Percentage of total cost
Human anti rabies vaccine	63,775(45,002-84,850)	47.86%
Wound treatment	920(724-1,140)	0.69%
Tetanus toxoid	662 (511-815)	0.49%
Hospital administration	1,763 (1,477-2,057)	1.32%
Travel while seeking PET	4,495 (3,150-5,696)	3.37%
Boarding while seeking PET	54,110(52,238-55,634)	40.61%
Productivity loss	7,528 (6,283-8,671)	5.65%
Total cost	133,253 (94,832-227,785)	

Table 4. 5: Cost for rabies PEP estimated from human dog bite cases reported from household questionnaire survey and based on the WHO recommended PEP schedule. The cost is based on the entire vaccination comprised of 145 villages with 466,989 humans.

Cost item	Amount (\$) (95% confidence interval (CI))	Percentage of total cost
Human anti rabies vaccine	(76,830-151,168)	20.47
Human rabies immunoglobulin	363,331 (327,937-396,603)	66.75
Wound treatment	918(729-1,144)	0.17
Tetanus toxoid	665 (516-809)	0.12
Hospital administration	1,771(1,475-2,071)	0.33
Travel while seeking PET	4,552 (3,674-5,216)	0.84
Boarding while seeking PET	54,126 (53,171,55,127)	9.94
Productivity loss	7,514 (6,554-8,520)	1.38
Total cost(\$)	544,289 (467,274-643,759)	

4.2.6. Indirect non medical rabies costs

On average dog bite victims were found to spend 6 (95%CI: 4-8) days seeking and receiving PEP. Over 88% of all dog bite victims who attended either a hospital or health centre were accompanied by an adult person (person over 18years of age). Victims under 16 years old were always accompanied by one adult person for treatment seeking and PEP. Adults, on the other hand, were accompanied by another adult person at least for one day out of the six days. The value of productivity loss suffered amounted to \$ 7,514

4.2.7. Direct non medical costs

Human bite victims from suspected rabid dogs who attended hospitals for PEP paid an average of \$2.94 per day (95%, 2.09-3.78) for transport and \$1.33 per day (95% CI, 0.6-2.06) for accommodation, meals and other charges while seeking PEP. The same costs were incurred by accompanying persons. The costs which could have been avoided for direct non medical costs within the vaccination were estimated to be \$ 58,678 per 466,989 people equivalent to \$ 12,565 per 100,000 people.

4.2.8. Benefits of domestic dog mass vaccination campaign

Result of the cost benefit model are summarized in Appendix V indicating that the cost per DALY saved after 15 years of domestic dog vaccination will be \$10.5. Net benefits accruing from avoiding PEP were realized from the sixth year of the vaccination campaign through substantial reduction in number of bite victims from

suspected rabid dogs and PEP and also due to fewer dogs that would be vaccinated within the maintenance phase of the campaign.

4.3. Discussion

One of the important questions likely to be faced by public health policy makers in relation to rabies control in Tanzania and Africa at large is likely to be related to a decision of whether to invest the scarce public health resources in controlling animal rabies or provide human PEP. This study demonstrates that controlling canine rabies would be an economically effective rabies control strategy that could result in a substantial net public health benefits in terms of savings on PEP expenditures. However, due to logistic constraints this study explored only a single scenario although further studies to investigate different scenarios of cost-benefit analysis for Tanzania are currently underway. The study also demonstrates that central point vaccine delivery approach offers an effective vaccine delivery strategy for rural agro-pastoral communities in Tanzania with the *per capita* cost for dog vaccination consistent with that obtained in other countries of the developing world (Fishbein *et al.*, 1991; Edelsten, 1995; Kayali *et al.*, 2006). However the central point vaccine delivery approach was not a viable strategy in remote pastoral Maasai communities with the coverage attained in this study well below the recommended target for rabies control and the *per capita* dog vaccination cost higher in comparison with the agro-pastoral communities. In the pastoral Maasai communities households are dispersed, the population is nomadic and dogs are not generally restrained (ie tied). This combination of factors is likely to make it difficult for individuals to bring dogs to a designated central vaccination point. This finding raises important questions on the design and implementation of dog vaccination campaigns in remote pastoral communities particularly on the blanket applicability of central point dog mass vaccination campaign against rabies. The finding highlights the need for

identification and utilization of alternative rabies control strategies for the pastoral community settings.

Accurate estimates of the *per capita* costs of dog vaccination are needed to plan effective and sustainable rabies control programmes. The cost of CP vaccination in agro-pastoral communities (US\$1.73 per dog) compares well with studies reported elsewhere, which vary between US\$1.19 to 4.27 in the Philippines (Fishbein *et al.*, 1991) and approximately US\$1.3 in Tunisia and Thailand (Bogel & Meslin, 1990). The *per capita* cost of dog vaccination in the agro-pastoral communities is likely to be even lower for a country-wide vaccination campaign due to economies of scale. The *per capita* costs of the most effective and economical strategies in pastoralist communities are considerably higher (> US\$6 and 4/dog with combined CP- HH and CP-CAHW strategies respectively). Substantially more resources will therefore be needed to control rabies in these areas, although the impact of vaccination is likely to be large because population densities are low. Individuals in remote pastoral communities are also likely to be at a greater risk of developing rabies following exposure because access to health care is limited (Chapter III). Therefore, the benefits of dog vaccination in these areas are considerable, despite the high costs.

Although the combine CP-HH vaccination strategy exceeded the recommended 70% coverage in the pastoral zone the *per capita* dog vaccination cost was higher compared to the combined CP-CAHW strategy. The HH component of the combined CP-HH strategy was also operationally difficult, vaccinating each dog was time consuming and required substantial investment in labour and capital. It may therefore

be difficult for this strategy to be undertaken independently and sustained by most district veterinary offices in Tanzania given the limited labour and financial resources.

Most Governments in Africa have largely failed to deliver sustainable veterinary services to remote pastoral locations; hence the initiation of CAHW approaches in several African countries. Previous research has demonstrated that well-coordinated, large-scale CAHW systems can form the basis for improved and effective livestock vaccine delivery strategies that compare favourably with and even surpass vaccination efficiencies achieved by government veterinary services (Jones *et al.*, 2005). The effectiveness of the CAHW model in areas with limited government veterinary services, logistical problems, and poor infrastructure demonstrates their potential as alternative service models for the veterinary sector where conventional models have failed. This study suggests that the combined CP-CAHW strategy has the potential to increase the coverage and cost-effectiveness of rabies vaccination strategies in remote pastoral communities.

This study demonstrates the importance of rabies as a multi sectoral disease affecting both the public health and veterinary sectors. Although not quantified in this study rabies has also been documented to have a substantial impact on wildlife conservation and livestock production. The control of the disease therefore calls for concerted multi-sectoral strategy with the animal health, wildlife and public health sectors taking the lead. The disease is completely vaccine preventable through mass

vaccination of domestic dogs and the substantial amount of resources invested in PEP could be avoided and utilized for other expenditures.

Chapter V: The impact of multi-valent vaccination of domestic dogs against rabies, canine distemper virus, canine parvovirus and canine hepatitis on domestic dog demography in rural Tanzania

5.0. Introduction

The domestic dog remains the principal reservoir for rabies in Africa and major vector accounting for over 90% of human deaths in the region and responsible for spill-over of rabies infection to wildlife in some protected areas (World Health Organization, 1989; Laurenson *et al.*, 1997; Cleaveland & Dye, 1995; Meslin *et al.*, 1994). Control measures against rabies in most of the developing countries are therefore targeted specifically against the domestic dog population. Empirical and theoretical studies recommend 70% as the critical vaccination coverage for rabies control by mass vaccination of domestic dogs (World Health Organization, 1987; Coleman & Dye, 1996). This critical coverage level is however rarely achieved in most vaccination campaigns implemented in the developing world due to, among other things, low accessibility of domestic dogs for parenteral vaccination (Perry *et al.*, 1995; Bogel & Joshi, 1990). Even where relatively higher coverage levels have been achieved, they often decline rapidly due to high turn over rate of dog populations in the developing world (Kitala *et al.*, 2001; Cleaveland, 1996; Brooks, 1990). Demographic processes that occur in dog populations therefore are likely to play an important role in determining the effectiveness of dog vaccination programmes and may provide key guidelines critical to making strategic management decisions in rabies control programme that involve mass vaccination of domestic dogs.

Population-level demographic variables depend on the properties of individuals that comprise the population. The two most basic parameters of a population are survivorship and fecundity rates. In most species both of these parameters vary with

the animal age (Pianka, 1999). For instance it is recognized that very young and very old individuals often do not breed, and very young individuals often have increased chances of dying. These basic parameters can be combined in a life-table, as age-specific survivorship and age-specific fecundity, from which the rate of population growth and projection of future population sizes can be derived (Pianka, 1999; Caughley, 1997).

Some of the major parameters estimated by demographic analysis from fecundity and survival rate schedules are the intrinsic (r) and finite (λ) rates of population increase, which measure the potential for growth rate in a population. In East Africa, studies in Kenya and Tanzania (Cleaveland, 1999; Kitala *et al.*, 2001) have estimated the intrinsic rate of increase of domestic dog population using a Euler-Lotka life table model.

Leslie introduced matrix algebra in the analysis of the dynamics of age-structured populations whereby population growth and age distribution can be estimated from the population age specific vital rates describing survival and fecundity of individuals in each age class (Leslie, 1948). The Leslie matrix model has been used in several studies to estimate the population intrinsic and finite rates of increase (Caswell, 2001). Although the Leslie matrix models forms one of the WHO recommended approaches (World Health Organization, 1988) it has never been used previously to estimate dog population growth rate.

Dog demographic parameters such as population size, fecundity, mortality and survival rates are crucial for the efficient design and implementation of rabies control programmes by dog vaccination. Estimation of population size for instance is essential to predict the number of vaccine doses required (Perry, 1995). Mortality and fecundity rates may be used to estimate the dog population growth and turn-over rates allowing critical inter-vaccination intervals to be determined. In rural Tanzania for example, the use of fecundity and survival schedules have demonstrated that the dog population in northwest Tanzania was growing at a rate ranging from 5-10% in the early 1990s, which was disproportionately faster than that of human populations (Cleaveland, 1996). Similar observations have been noted in Zimbabwe and Kenya (Kitala *et al.*, 2001; Brooks, 1991). By using the information on population growth and turn over rates the frequency of rabies vaccination campaigns can be determined. In Tanzania, for instance, the conventional practice of annual rabies vaccination campaign has been questioned based on information on dog population growth and turn over rates which suggest vaccination campaigns should be repeated 6-8 months in order to maintain vaccination coverage above the recommended 70% threshold (Cleaveland, 1996). However both studies in Tanzania and Kenya were small scale and based on a limited geographical area, highlighting the need for more rigorous study involving a large scale and geographically wider investigation.

5.1. Survivorship schedule

Survivorship schedules describe the probability of surviving through each age class and can be determined in two basic ways: a) using the cohort method whereby a set

of individuals is observed longitudinally through time from beginning to end of observation time b) using the static method, also known as segment method, whereby the number of individuals of each age class present in a population is recorded at once in a cross-sectional survey (Pianka, 1999; Caughley, 1997). Of the two survival estimation approaches, the cohort method is more rigorous and is more commonly used to estimate survivorship in different mammalian species. The cohort approach has been used in Kenya and Tanzania to estimate the survival rates of domestic dog populations (Cleaveland, 1999; Kitala *et al.*, 2001).

5.1.2. Fecundity schedules

Fecundity, which is the potential rate at which an organism reproduces, is defined as the number of female(s) born per female per year (Pianka, 1999; Caughley, 1997). Mammalian age patterns of fecundity are thought to fall into two types: a) those displaying reproductive senescence and b) those that do not senesce. In general, domestic dog fecundity in Africa has been shown to display a significant pre-reproductive period followed by a rapid increase in fecundity with age to a maximum and finally a decline (Cleaveland, 1996; Kitala *et al.*, 2001). However it has been reported that domestic dogs in rural Africa exhibit short life expectancy (Cleaveland, 1996; Coleman, 1999). This makes precise estimation of the age pattern of domestic dog fecundity at older age particularly difficult as there are only a few dogs that survive to old age. In addition even those that do survive to old age do not show a significant post-reproductive phase. Consequently domestic dog age pattern of fecundity at the older age is likely to incorporate a substantial degree of random error.

5.1.3. Age distribution

The age distribution indicates the proportion of a population belonging to each age class. The population age distribution is known to have an important bearing on the population growth rate. It is understood for example that two populations with identical survival and fecundity schedules, but with different age distributions, will behave differently and may even grow at different rates if one population has a higher proportion of individuals in the reproductive age class. A population with relatively unchanging fecundity and survival schedules eventually gives rise to a population with a stable age distribution (Pianka, 1999;Caughley, 1997). When a population reaches this equilibrium age distribution, the proportion of individuals in each age group remains constant and recruitment into every age class is exactly balanced by its losses due to mortality and aging.

5.1.4. Dog population size estimation

Some of the commonly used approaches for estimating animal population size include i) mark-recapture technique and ii) line transect. These methods are based on counting individuals as a random sample and estimating the total population size from the obtained sample. Detailed reviews on the various approaches for estimating animal population sizes are available elsewhere (Blower *et al.*, 1981; Caughley, 1997). The various population estimation techniques functions only under a set of assumptions. Any violation of these assumptions is likely to result in a biased estimate of the population size. For mark-recapture technique important assumptions include: i) a

completely random animal population where every individual in the population has an equal chance of being captured ii) a closed population so that there is no change in the ratio between marked and unmarked individuals during the interval between marking and re-capture iii) marked animals, when are released back into the population, distribute themselves randomly. For distance sampling the key assumptions underlying the approach include i) the requirement for animals on the observation line to be detected with certainty ii) objects need to be detected at their initial location and iii) measurements need to be exact. Some of the problems likely to be associated with these techniques include i) Different degree of efforts when there is more than one observer involved ii) Failure to detect subjects in forested habitat iii) Some subjects are likely to move undetected away or towards the line of observation. The advantages of these sampling techniques include: i) the ability to estimate population size from a sample ii) population size can be estimated from data collected by more than one observer even if one of these observers missed some subjects away from the line iii) only a relatively small percent of subjects need to be detected within the sampled area iv) the size of the sample area can be unknown. The type of method used depends largely on the nature of population being investigated. For domestic dog populations some of the conventional approaches which have been used to estimate population size include the line transect method and mark-recapture (Childs *et al.*, 1998; Anvik *et al.*, 1974; Matter *et al.*, 2000). An additional method which is generally unique for domestic dogs is the human-to-dog ratio approach (World Health Organization, 1988; World Health Organization, 1990). The human-to-dog ratio was used in this study.

The information about dog population size is required to enable proper planning, implementation and evaluation of dog vaccination campaigns. Dog population size for instance may be required for estimating the number of vaccine doses required in a given area, the accessibility of dogs for parenteral vaccination and estimation of vaccination coverage levels achieved (Perry, 1995, Childs *et al.*, 1998). However, some conventional approaches for estimating dog population size may not be applicable under all conditions. In some parts of rural Tanzania for instance the mark-recapture approach was shown to be logistically difficult and inappropriate due highly dispersed households and small size of dog populations (Cleaveland, 1996) highlighting the need for different approaches in different settings. The dog-to-human ratio is however the most commonly used approach for estimation of dog population size.

5.1.5. Dog population growth rate and control

Domestic dog population growth rate is an important demographic parameter of relevance to vaccination strategies in terms of estimating the inter-vaccination interval, population vaccination coverage and to determine the likelihood of generating feral dog population. In a domestic dog population where the population growth is faster than coping capacity of dog owners there are higher chances of developing a relatively high proportion of free ranging dogs as extra dogs generated are likely to be abandoned and therefore enter the free ranging dog population, although the impact of abandoned dogs is likely to be countered by their low chances of survival. Studies on dog population have suggested a number of measures implemented by dog owners to keep dog population under control. Leney and

Remfry (2000) suggested prevention of bitches from breeding and killing of surplus puppies as measures undertaken by rural dog owners to keep the dog population under control.

The impact of vaccination on dog demography has not been adequately investigated. If important diseases such as parvo virus, canine hepatitis and canine distemper exist in dog populations, vaccination that provides protection against them is likely to result in marked improvement in the health of dog population resulting in increased survivorship, thus leading to substantial growth of dog population. This is especially likely to occur in most of rural settings where dog are allowed to roam freely and owners do not exercise population control measures (Kitala *et al.*, 2001; Butler, 1995; Wandeler *et al.*, 1988). Uncontrolled increase in dog population is likely to result in undesirable consequences including rabies transmission, haphazard human biting, frightening the public and environmental pollution through dog faecal and urine contamination. This may necessitate execution of even more expensive dog population control measures such as dog culling which is considered to be counterproductive.

In the more developed world, dogs are generally categorized as either 'pets' or 'stray' depending on their ownership status. However, for most of the developing world this "western" categorization is likely to be inappropriate. Studies have shown that in some communities, dogs are avoided due to fear and dislike, in others, dogs are tolerated and coexist with human and in others they live in a symbiotic relationship (Wandeler *et al.*, 1998). Such wide range human-dog relationship is therefore likely

to be complex and varied when compared to developed countries. The World Health Organisation (WHO) has highlighted this complexity by establishing a matrix of dog categories based on the dog's level of dependence (i.e. intentional provision of resources) and level of restriction by man (World Health Organization, 2004). These categorizations are:

1. Restricted (supervised) dogs - fully dependent and fully restricted by man
2. Family dogs - fully dependent and semi-restricted
3. Neighbourhood dogs - semi-dependent and semi-restricted
4. Unrestricted (unsupervised) dogs - semi-dependent and unrestricted
5. Feral dogs - independent and unrestricted

The World Health Organization uses the term “street dog” to refer to categories 2 up to 5. Such street dogs often retain a large degree of autonomy and the community does not have the same responsibility and liability expectations of pet ownership that are evident in developed world. Category 1, which is considered similar to the Western model of pet ownership, is a relatively new but growing concept in most of the developing world and is mainly reserved for particular breeds that are perceived to be 'special' (M.Kaare, pers observ). Street dogs are less likely to be reproductively capable of maintaining their population density unless food and shelter are provided by man (Daniels, 1982). Such provision may be intentional or non-intentional, in the form of open garbage dumps and empty buildings.

Both public health and animal welfare concern are given as reasons for controlling dog populations. Spread of zoonoses such as rabies is a particular problem where high densities of dogs and humans live in close association (World Health

Organization, 1988). Dog welfare is also likely to be poor if the population is not controlled due to competition for limited resources, leading to malnourishment in some individuals, particularly in pregnant and lactating bitches and also a high rate of spread of infectious disease and parasites (Bojrab, 1998).

Dog population control measures continue to form a component part of rabies control strategies in various countries. The major approach for dog population control has been killing of free roaming dogs through various means including shooting and poisonings. The World Health Organisation (WHO) now recognises that killing of free roaming dogs is not effective in controlling dog population (World Health Organization, 2004). Even the recorded maximal dog removal rates of up to 24% of dog population per year have been document to be ineffective (World Health Organization, 1988; World Health Organization, 1990). Where dogs are removed, others migrate into the area to fill the ecological niche (Szasz, 1969). In addition, killing is expensive and often not acceptable to the local community (World Health Organization, 1988; World Health Organization, 1990). Recent recommendations advocate habitat control and control of the birth rate by reproductive sterilisation of dogs by castration, ovariectomy or delivery of hormonal contraceptives (World Health Organization, 1990; World Health Organization, 2004). These dog population control measures if combined with effective mass vaccination of domestic dogs against rabies are likely to create a relatively stable and immune dog population and hence resulting into marked reduction of rabies incidence. In some Asian countries such as India where rabies is endemic, dog sterilization programmes

accompanied by vaccination of sterilized dogs and habitat control are reported to have resulted into significant reductions in the number of unsupervised dog , human bite injuries and up to 100% reduction of human rabies cases (World Health Organization, 2004; Reece & Chawla, 2006). Although several animal birth control (ABC) programmes have recently been implemented in Asia there is still lack of robust data in terms of their impact on dog demography and rabies incidence. In additional detailed evaluation of the ABC programmes cost-effectiveness still need to be adequately addressed.

In this study we describe the demography of rural dog population in northwest Tanzania by estimating some of the important demographic parameters including the dog population growth rate, sex and age distribution, fecundity and survivorship schedules. The study also evaluates the impact of multivalent rabies mass vaccination on dog survivorship and growth rate.

5.2. Materials and method

5.2.2. Study area

The study was carried out in the area already described previously (Chapter II).

5.2.3. Age structure

Information was collected on the age of dogs by asking dog owners the age of their dogs in a household questionnaire survey (Chapter II). In order to validate the ages given, owners were asked to correlate the age of the dog with an important memorable event in a household, village or region, such as the start of farming season, opening of schools, when a child started a particular class in school, village election time, famine or other memorable events. This was done with the help of a local assistant from each village who accompanied the interviewer. Ages were recorded in years and then converted into months. For analysis dogs were classified in months into discrete seven age classes as follows: 0-3 months, 4-12 months, 13-24 months, 25-36 months, 37-48, 48- 60 months and above 60 months. Dogs in the 0-3 months age class were classified as puppies, those between 4- 12 months were classified as juveniles and those above 12 months were classified as adults. In order to assess the respondent and interviewer bias, the same respondents were re-interviewed within seven days by a different interviewer and both respondent and interviewer consistency compared. Ages collected on the re-interview questionnaire were compared with those given on the first interview to evaluate if the degree of inconsistency in ages resulted into significant impact in distribution of dogs into age classes.

5.2.4. Fecundity

Data were collected over a three year period in 2003, 2004 and 2005, in the household questionnaire survey (Chapter II) which corresponded to the three vaccination campaigns, on the number of female dogs present in each household and their reproductive parameters, which included number of births in female dogs, whether the dog has given birth in the past one year and the litter size. Dogs were categorized into seven age classes as follows: 0-3 months, 4-12 months, 13-24 months, 25-36 months, 37-48 months, 49-60 months and above 60 months. The mean litter size of each age class was determined from questionnaire data and fecundity schedules constructed for the entire vaccination, and control zones and LGCA. Female dog reproductive data was used to estimate age specific fecundity rates over a three year period. For year 2005 the LGCA fecundity data for age class above 60 months could not be estimated due low sample size.

5.2.5. Age specific mortality and survivorship

Age specific mortality and cumulative survival was estimated by the product limit method (Kaplan & Meier, 1958) from data collected in the year 2003, 2004 and 2005 in the agro-pastoral control zone and year 2004 and 2005 in the agro-pastoral vaccination zone and LGCA through cross-sectional and longitudinal household questionnaire surveys (Chapter II). Although there was no control zone in the LGCA, the 12 month retrospective fertility and mortality data collected in year 2004 allowed estimation of pre-vaccination survival and mortality rates. For the agro-pastoral vaccination zone the questionnaire survey conducted in year 2003 did not include

specific questions to allow for the estimation of pre-vaccination survival and mortality rates. Mortality in puppies (dogs \leq 3 months old) was estimated from fertility data described previously (Chapter II). In order to reduce recall bias, neonatal mortality was estimated only from litters born at least three months previously from the date of questionnaire survey. Juvenile and adult dogs (dogs $>$ 3 months old) were treated separately and grouped in age classes as described previously in this chapter. In the cross-sectional household questionnaire survey information was collected on dogs which died within past 12 months including the age at death and death date. This allowed conversion of cross sectional data into longitudinal mortality data which extended one year retrospectively from the date of questionnaire administration.

In order to evaluate the impact of the vaccination programme on dog mortality and survivorship at a population and individual dog level, a comparison of dog survival rates between the control and vaccination zones and within the vaccination zone dog populations was undertaken. For the LGCA a comparison was made between the pre-vaccination and post-vaccination survival and mortality rates. The effect of age class, district, zone and vaccination status on dog survivorship was investigated using the Cox Proportional Hazard multiple regression analysis (Crawley, 2003) in the statistical software *S-Plus* (SPLUS 2000 Professional, Insightful, Seattle, WA) whereby survivorship was modeled as function of dog vaccination status, dog age class and zone (control and vaccination). The proportionality of covariate hazards was investigated by plotting a graph of log-cumulative of hazards in *S-plus* software.

5.2.6. Estimation of dog population size

The dog population size was estimated from dog-to-human ratio obtained in this study for year 2003 in the agro-pastoral vaccination and control zone and year 2004 for the LGCA. The dog-to-human ratio for owned dogs was estimated from the post vaccination household questionnaire survey described previously by dividing the total number of people by total number of dogs for each village to obtain village level dog-to-human ratio. The village dog-to-human ratios were then sampled iteratively 1,000 times using bootstrap technique (Crawley, 2003) in the statistical software *S-Plus* (SPLUS 2000 Professional, Insightful, Seattle, WA) in order to obtain the mean dog-to-human ratio for the whole population with 95% confidence interval. The human population was obtained from the year 2002 population and census data and projected forward at a growth rate of 2.9% per year (Tanzania National Bureau of Statistics, 2005).

5.2.7. Population growth rate

Leslie matrix models were used to estimate the intrinsic (r) and finite (λ) rate of domestic dog population growth and proportion of female dogs that needs to be sterilized in order to stabilize the population so that the age distribution of the population remains constant over time. The model considered only female dogs in the population. The population was categorized into discrete one year age classes and assumed that individual dog's chance of surviving from one year to the next is a function of its age. The model was parameterized as a discrete birth pulse deterministic model using the survival and fecundity rates obtained in the present study to. The variables and parameters of the model are as follows:

- L_x probability of surviving from age x to age $x+1$
- S_x average numbers of offspring produced by one female in age interval x to $x+1$
- $N_{x,t}$ number of female dogs in age x at time t ,
- p proportion in an age class that is breeding
- g proportion to be sterilized

The basic formula for the Leslie Matrix model is:

$N_{t+1} = AN_t$, where A is a transitional matrix indicated below:

$$A := \begin{bmatrix} 0 & 0 & p_2 \cdot (1-g) \cdot s_2 & p_3 \cdot (1-g) \cdot s_3 & p_4 \cdot (1-g) \cdot s_4 & p_5 \cdot (1-g) \cdot s_5 & p_6 \cdot (1-g) \cdot s_6 \\ L_0 \cdot L_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & L_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & L_5 & L_6 & 0 \end{bmatrix}$$

The matrix columns represent the age classes. The Leslie Matrix was adapted to include information on the proportion of breeding female dogs (g) that should be sterilized out of the total breeding female dog (p) in order to stabilize the population growth rate. The value of λ was determined by finding the dominant eigenvalue of A using Mathcard software.

If a population has a stable age distribution, λ will be constant over time, and each age class, as well as total population size, will grow according to finite rate of increase (λ). The finite rate of increase λ and the intrinsic rate of increase r are related through the following equations:

$$\lambda = e^r \quad \text{and}$$

$$\ln \lambda = r$$

In order to explore the community attitude towards changes in dog population and possible dog population control measures questions were included in the 2005 questionnaires survey to collect information on the community perception about any changes in the dog population size (increasing or decreasing), the maximum number of dogs which a household can keep and dog control measures that owner are likely to implement in case of any event that results in increased dog population.

5.3. Results

5.3.2. Age and sex distribution

Figures 5.1 to 5.4 show the age and sex distribution of domestic dogs in the agro-pastoral zone for years 2003, 2004 and 2005 within the vaccination and control zone with 48.4% (95% CI 45.9 to 50.8) of dogs being one year old or less. The sex distribution of the dog population demonstrated higher proportion of male dogs than female in each age class. The observation on age and sex distribution was consistently noted in years 2004 and 2005. The female to male ratio was 1:1.4 for year 2003 within the pastoral vaccination zone. Similarly in the pastoral Loliondo Game Controlled area the proportion of dogs below or equal to one year old formed 51.8% (95% CI 47.3 to 56.4) of the dog population and the female to male ratio was 1:1.5.

Figure 5. 1: Age distribution of domestic dogs in the vaccination zone for years 2003, 2004 and 2005

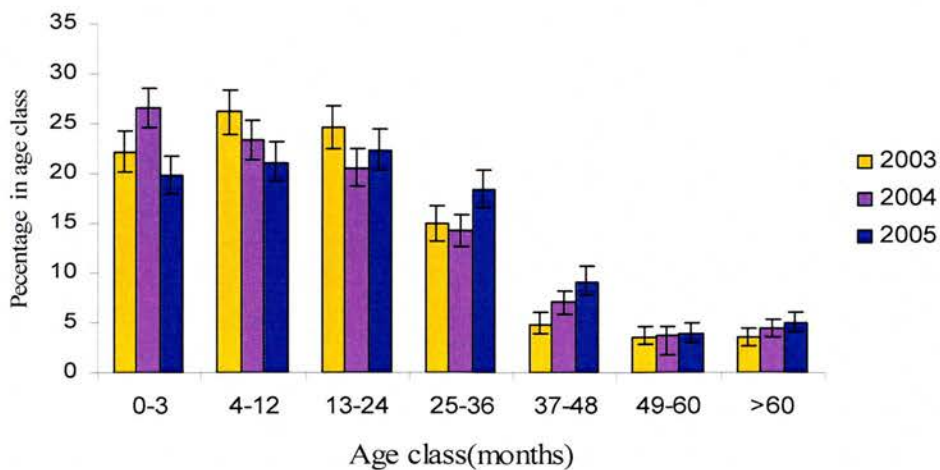
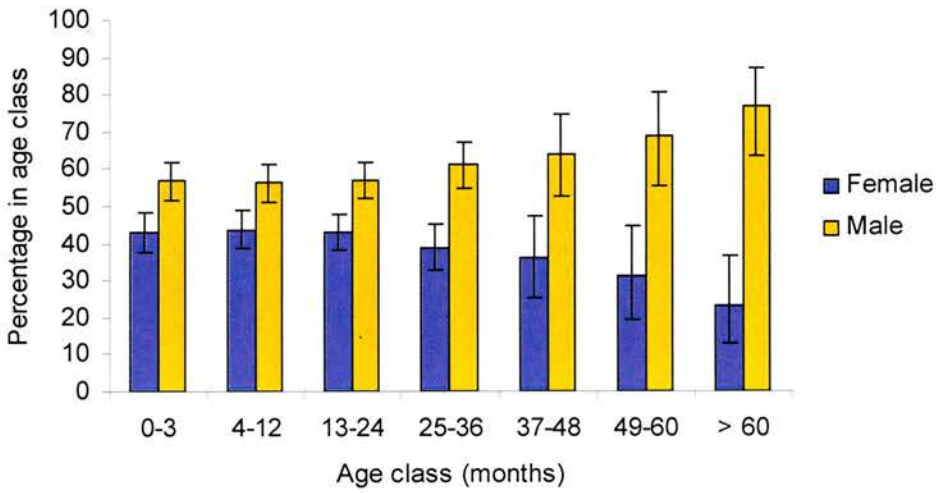
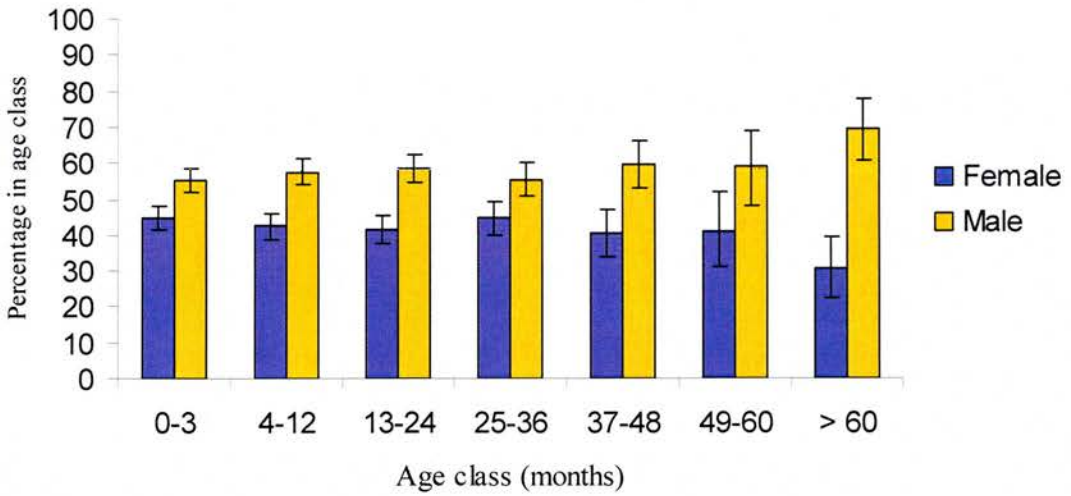


Figure 5. 2: Domestic dog sex distribution within the agro-pastoral vaccination zone

a. Year 2003



b. Year 2004



c. Year 2005

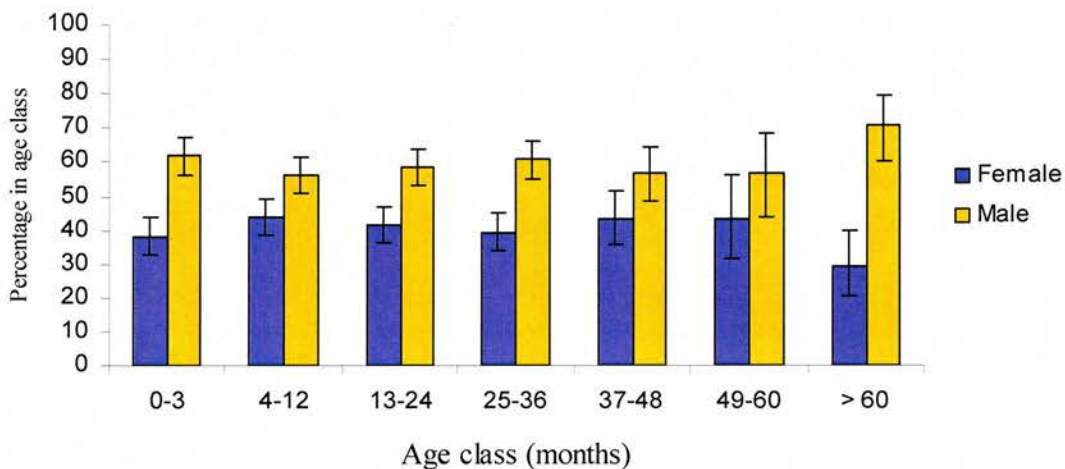


Figure 5. 3: Age distribution in the control zone domestic dog population for years 2003, 2004 and 2005

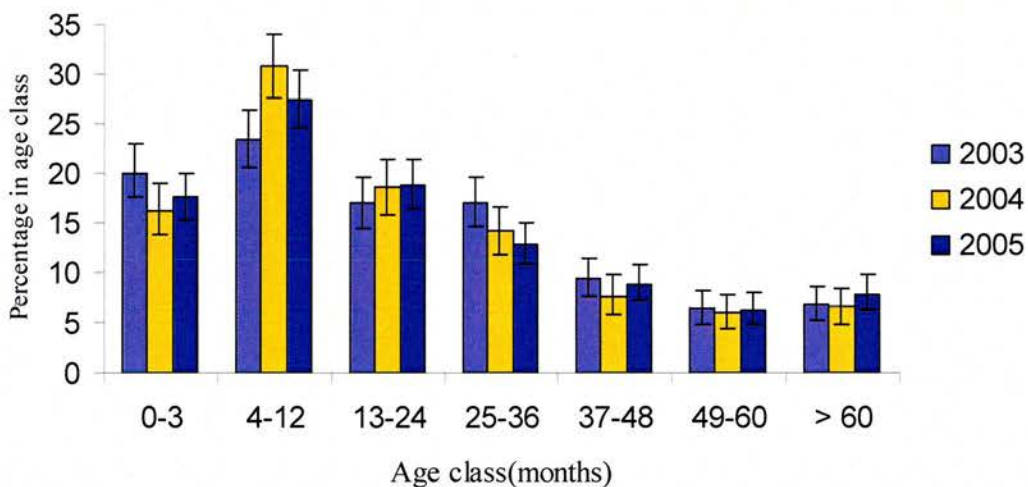


Figure 5. 4: Age distribution within the pastoral community Loliondo Game Controlled Area domestic dog population for years 2004

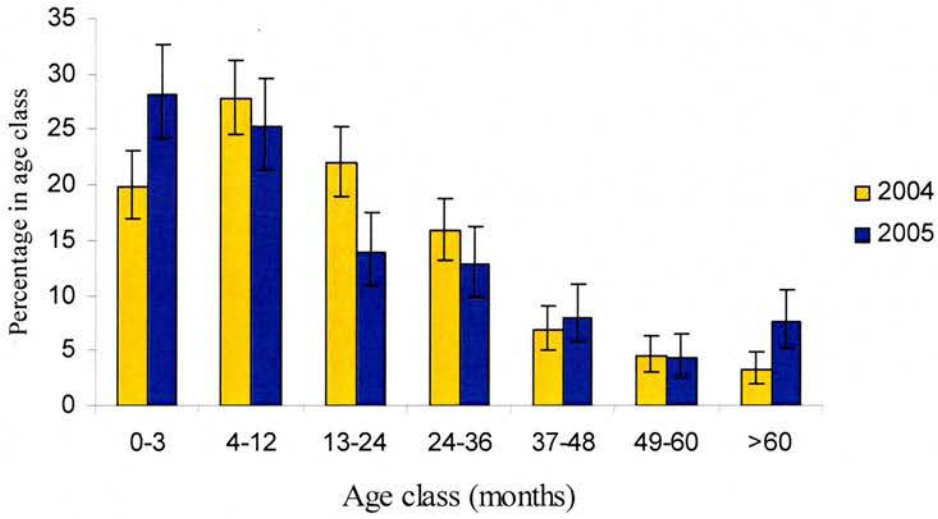
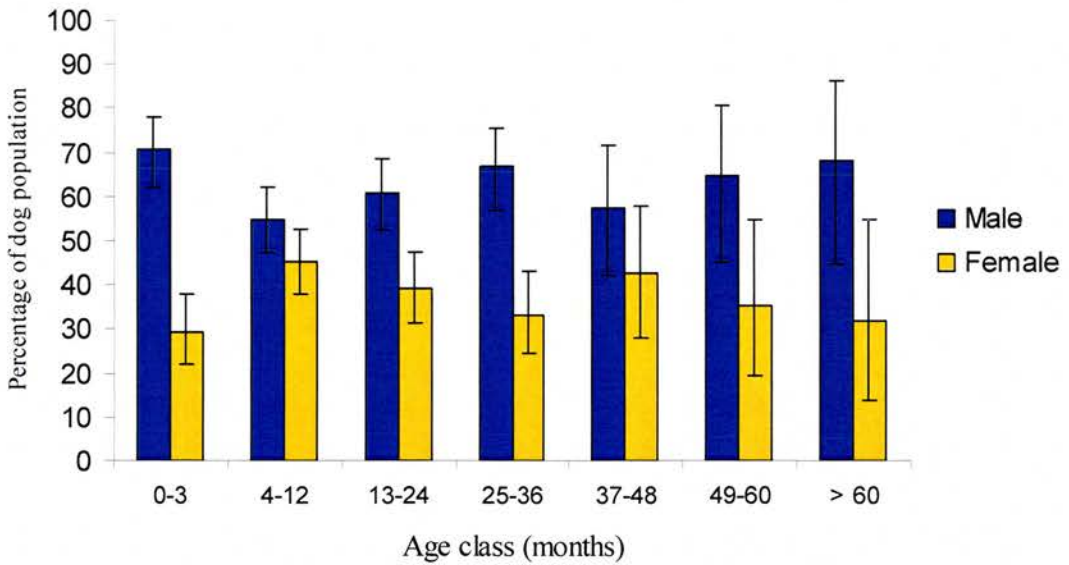


Figure 5. 5: Sex distribution of dog population within the pastoral Loliondo Game Controlled Area



5.3.3. Dog survivorship

The overall dog survivorship in the vaccination zone was 86.8% (95% CI 80.5-84) which was significantly higher ($p < 0.001$) than the overall survivorship of 67.2% (95% CI 85.3-88.3) in the adjacent unvaccinated dog population within the control zone. Vaccinated dogs within the vaccination zone showed a survival rate of 85.7% (95% CI 83.3-88.2) which was significantly higher ($p < 0.0001$) than the survival rate of 79.6% (95% CI 76.5-82.7) shown by unvaccinated dogs within the vaccination zone.

There was a significant difference in survivorship between age classes ($p < 0.001$) with pups (dog \leq 3 months) showing the lowest survival rate of 80% (95% CI 75.6-84.9) in the vaccination zone and 61% (95% CI 50.6-73.5) in the control zone. There was a significant difference in survival rates between sex with male dogs showing a survival rate of 85% (95% CI 82-87) which was significantly greater ($p < 0.001$) than the survival rate of 78% (95% CI 75-82) shown by female dogs.

In the pastoral Loliondo Game Controlled Area, the overall domestic dog survivorship was 83.2 (95% CI 80.3 to 86.1) which was significantly higher than that the survival rate observed in both the agro-pastoral control zone dog population ($p \leq 0.0001$) and agro-pastoral vaccination zone dog populations ($p = 0.002$). As in the pastoral areas, there was significant difference in survival rates ($p < 0.0001$) between age classes with puppies (dogs \leq 3 months old) showing the lowest survival rate of 66.7% (95% CI 59.6-74.6%). The survival rate for male dogs in Loliondo Game Controlled Area was 85.4% (95% CI 81.8 to 89%) which was significantly higher

($p < 0.0001$) than female survival rate of 80 % (95%CI 75.3 to 84.9). Kaplan-Meier Survivorship curves are shown in Figures 5.7 to 5.9. In the Loliondo Game Controlled Area the pre-vaccination survival rate was 83.2% (95% CI 80.3 to 86.1) which was not significantly different ($p = 0.74$) from the post vaccination survival rate of 84.8% (95% CI 81.4 to 88.5)

Figure 5. 6: Kaplan-Meier curve showing dog survivorship in the vaccination and control zone and Loliondo game controlled area

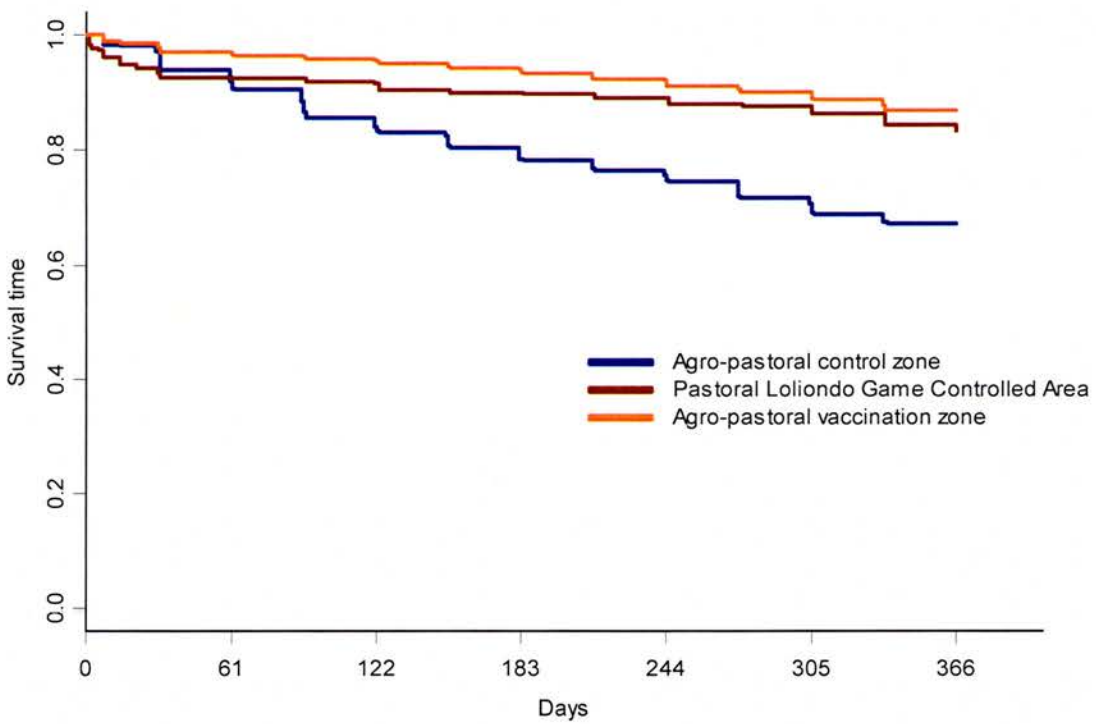
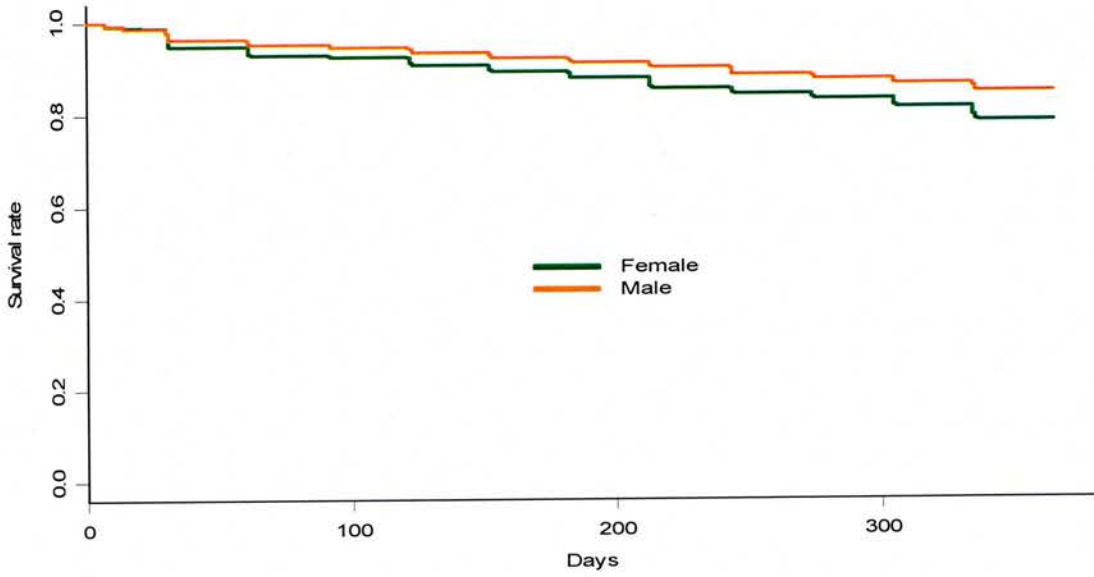


Figure 5. 7: Survivorship curve for female and male dogs estimated from household questionnaire survey

a. Vaccination zone



c. Pastoral Loliondo Game Controlled Area

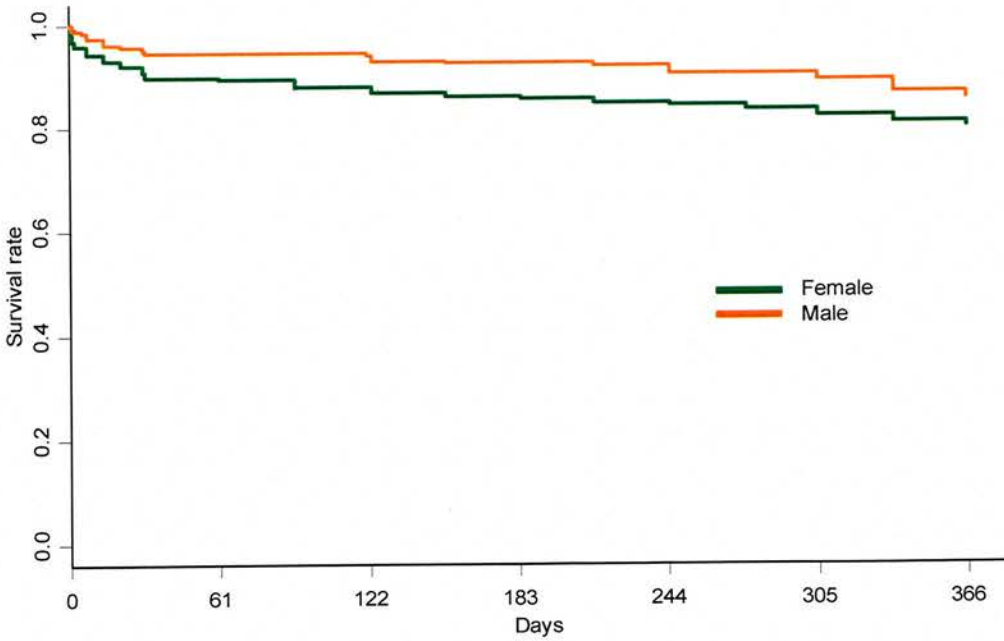
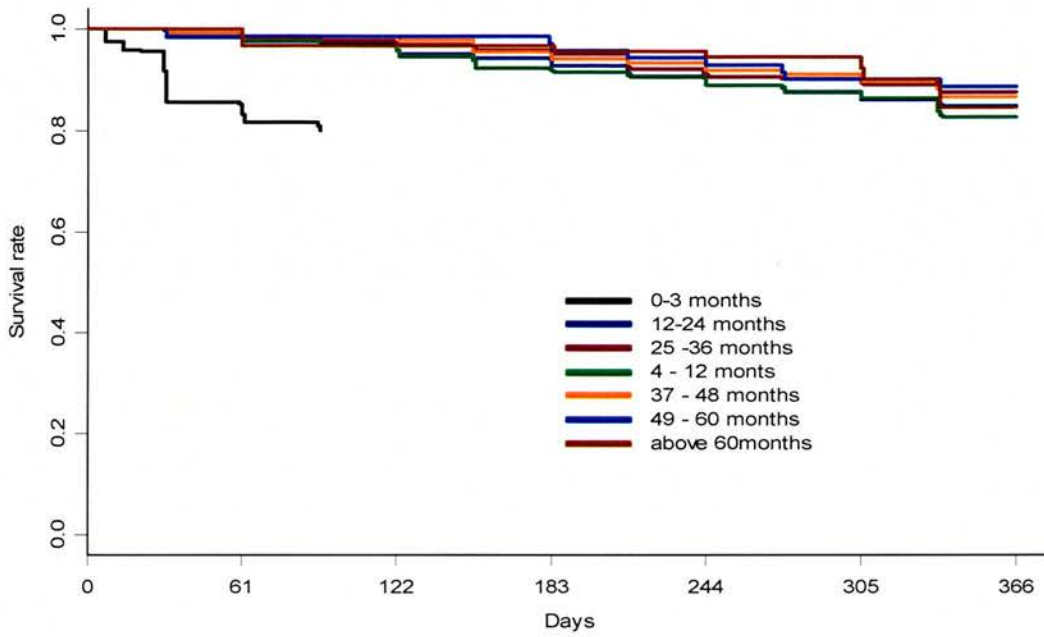


Figure 5. 8: Kaplan-Meier curve showing age specific survivorship in the vaccination zone for years 2004 and 2005 as estimated from household questionnaire survey

a. Year 2004



b. Year 2005

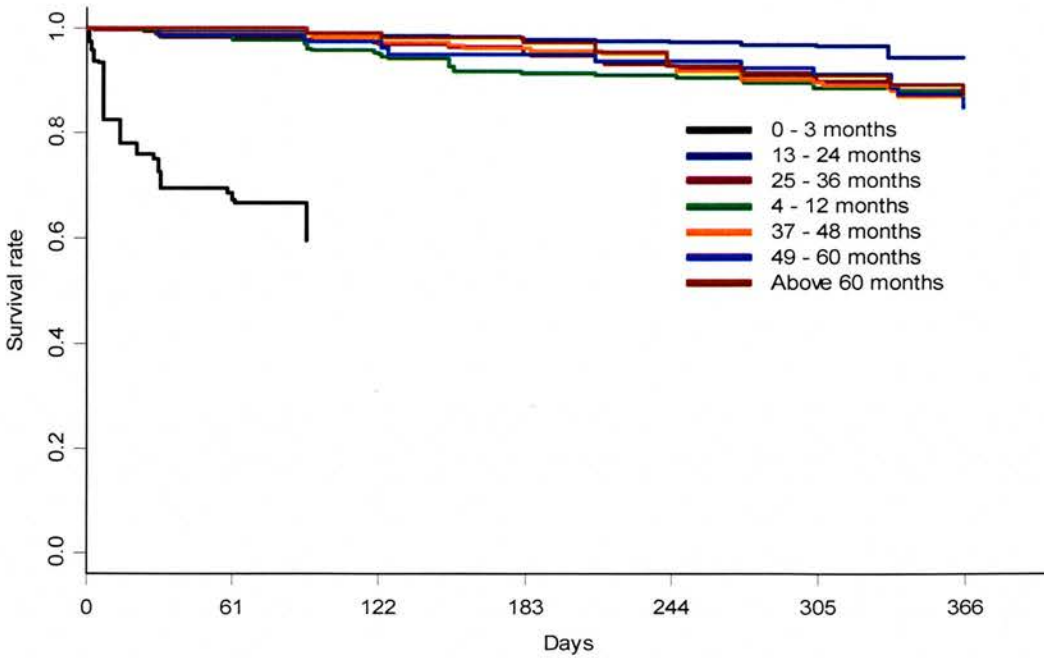
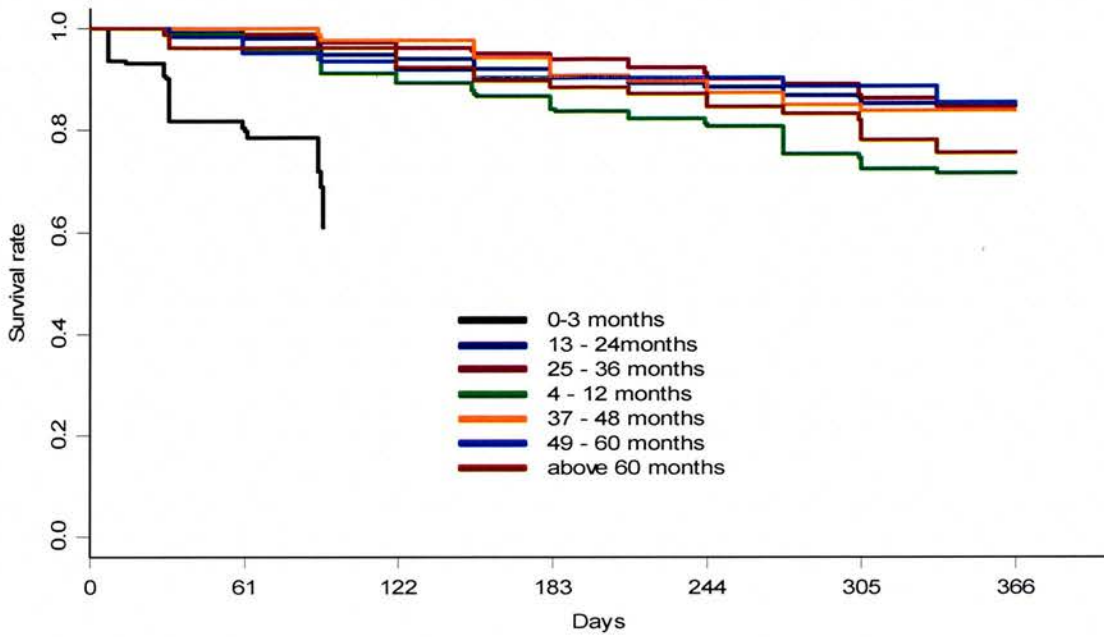
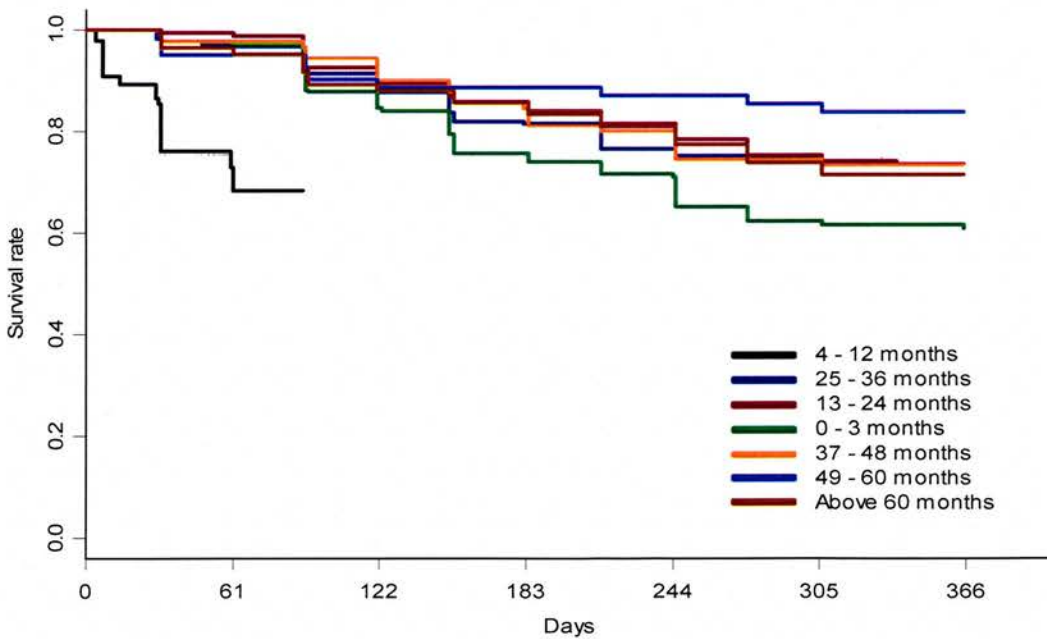


Figure 5. 9: Kaplan-Meier curves showing age specific survivorship in the control zone for years 2003, 2004 and 2005

a. Year 2003



b. Year 2004



c. Year 2005

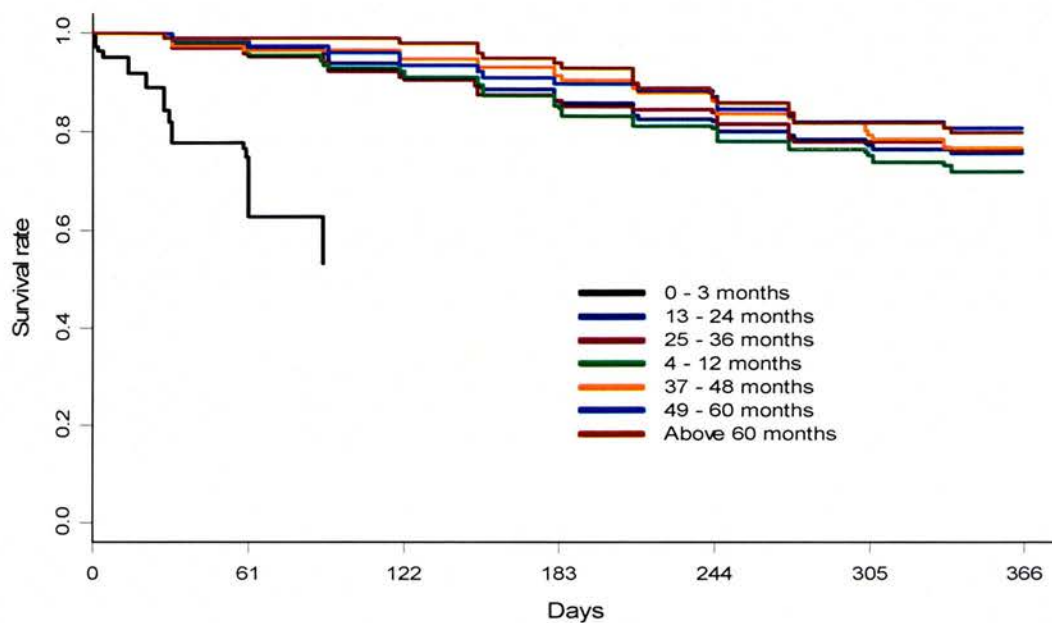
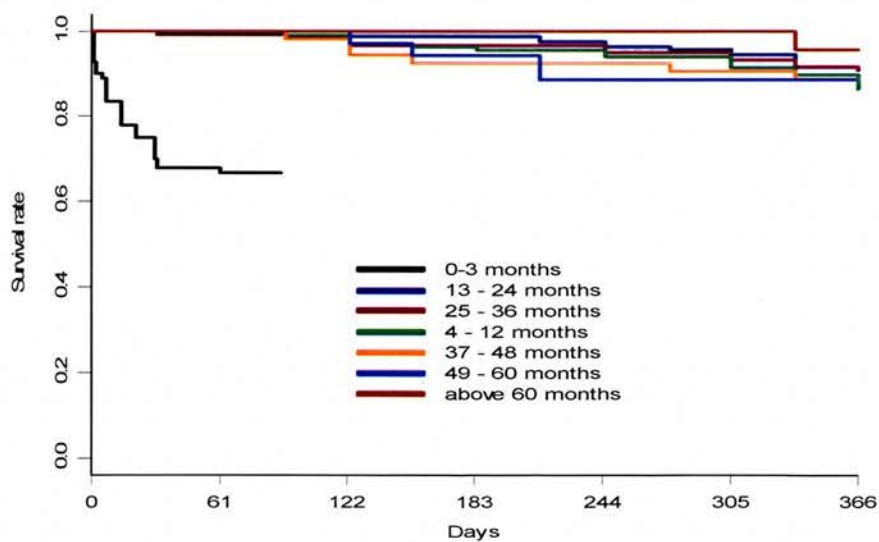
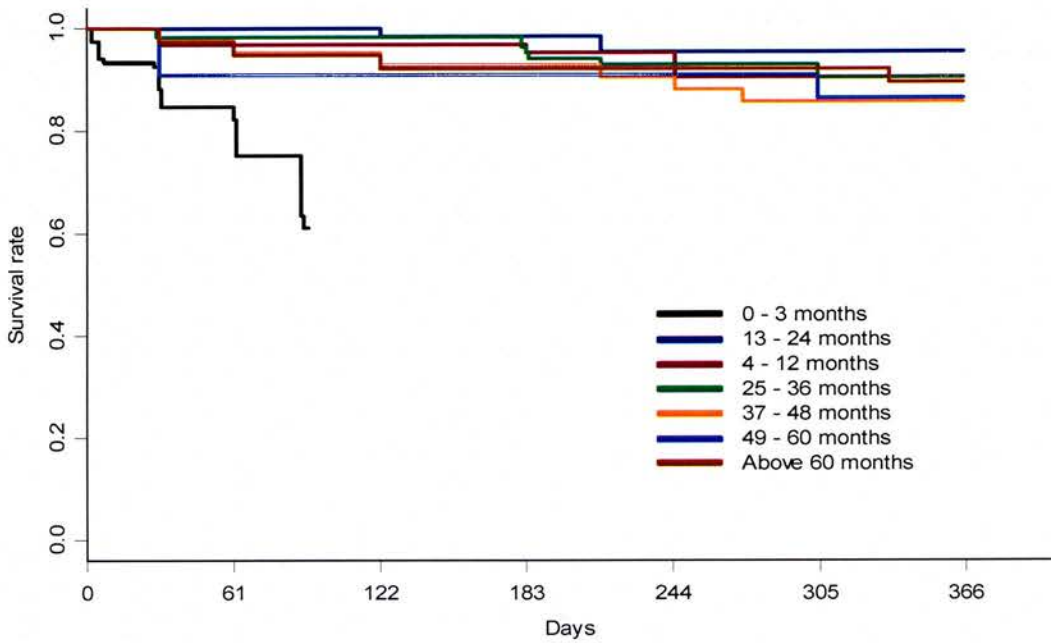


Figure 5. 10: Kaplan-Meier curve showing pre vaccination age specific survival rates of domestic dogs in Loliondo game controlled area pastoral community

a) Year 2003



b. Year 2004

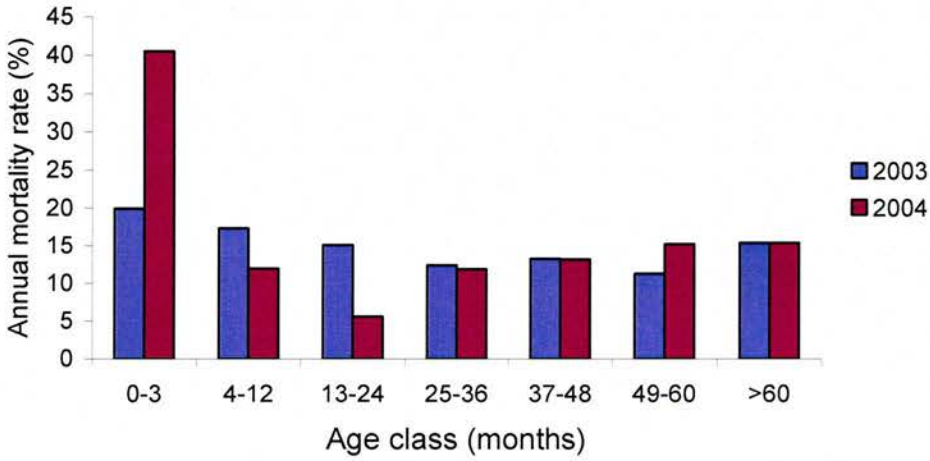


5.3.4. Age specific mortality rate

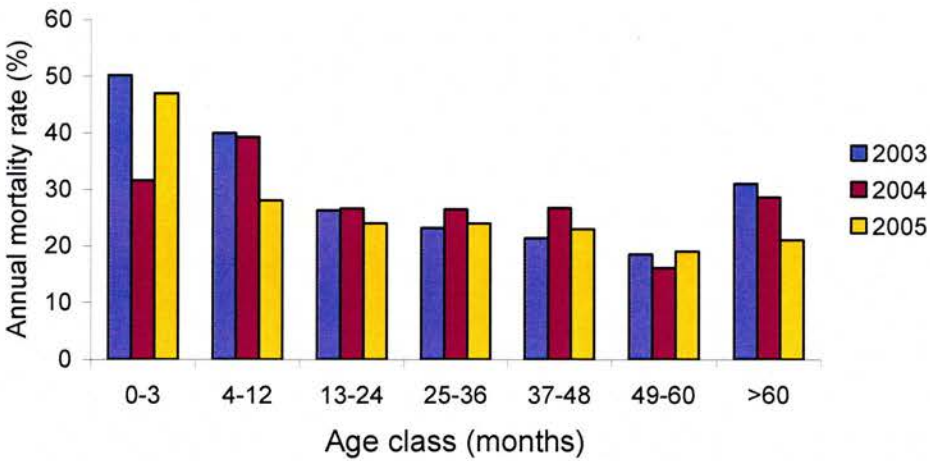
Overall mortality rate was higher in the control zone compared to vaccination zone. The overall mortality in the control zone was 32.8% (29.5-35.9) compared to 13.2% (95% CI 11.7- 14.7) in the vaccination zone. In the Loliondo game controlled area the overall mortality rate was 17% (95% CI 14-20). Age specific mortality for the control and vaccination zone is shown in figure 5.8.

Figure 5. 11: Age specific annual mortality rates. Neonatal mortality was determined from the fertility data in questionnaire survey whereas juvenile and adult mortality was determined from the longitudinal data

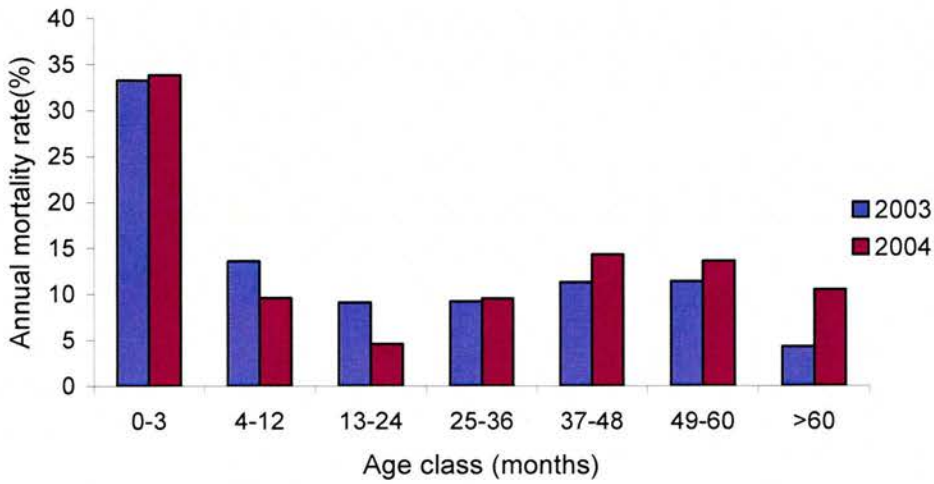
a. Vaccination zone



b. control zone



c. Loliondo game controlled area



5.3.5. Puppy disposal

Within the vaccination overall 26% (95% CI 23.8 to 28.2) of all puppies whelped die due to various reasons, 48.6 % (95% CI 46 to 51) are given away to other households, 0.06% are killed by dog owners and 25.4%(95%CI 23.4 to 27.7) are retained by owners.

5.3.6. Domestic dog life expectancy

Domestic dogs in the vaccination zone showed a life expectancy of 2.5 years which was longer in comparison with the 2.06 years life expectancy shown by domestic dogs in the control zone. Dogs in the Loliondo game controlled area showed a life expectancy of 2.8 years which was longer than that shown by dogs in both the control and vaccination zones. Life tables for domestic dog population in the

vaccination and control zones and that for Loliondo game controlled area are illustrated in Tables 5.1 to 5.3

Table 5. 1: Life table for dog population in the vaccination zone estimated from household questionnaire survey survival and fecundity data

a. Year 2003

Age class(months)	Survival rate L	Survival l_x	Months lived between age classes L_x	Yeas lived after age class T_x	Life expectancy e_x
0-3	0.801	0.801	0.74	3.09	3.80
4-12	0.827	0.662	0.61	2.35	3.55
13-24	0.849	0.562	0.53	1.74	3.09
25-36	0.876	0.492	0.46	1.21	2.46
37-48	0.867	0.427	0.40	0.75	1.76
49-60	0.887	0.378	0.35	0.35	0.92
Above 60	0.846	0.320			
MEAN LIFE EXPECTANCY					2.56

b. Year 2004

Age class(months)	Survival rate L	Survival l_x	L_x	T_x	Life expectancy e_x
0-3	0.595	0.595	0.56	2.59	4.35
4-12	0.880	0.524	0.51	2.03	3.88
13-24	0.944	0.494	0.46	1.52	3.08
25-36	0.881	0.435	0.41	1.06	2.43
37-48	0.868	0.378	0.35	0.65	1.72
49-60	0.848	0.320	0.30	0.30	0.92
Above 60	0.873	0.279			
MEAN LIFE EXPECTANCY					2.7

Table 5. 2: Life table for dog population in the control zone estimated from household questionnaire survey survival and fecundity data

a. Year 2003

Age class (months)	Survival rate L	Survival l_x	L_x	T_x	Life expectancy e_x
0-3	0.498	0.49	0.39	1.22	2.44
4-12	0.6	0.29	0.26	0.82	2.75
13-24	0.737	0.22	0.19	0.56	2.5425
25-36	0.768	0.17	0.15	0.36	2.16
37-48	0.786	0.13	0.12	0.21	1.61
49-60	0.815	0.11	0.09	0.09	0.84
Above 60	0.69	0.07			
MEAN LIFE EXPECTANCY					2.06

b. Year 2004

Age class(months)	Survival rate L	Survival l_x	L_x	T_x	Life expectancy e_x
0-3	0.68	0.68	0.55	1.64	2.39
4-12	0.61	0.41	0.36	1.09	2.62
13-24	0.73	0.31	0.26	0.73	2.39
25-36	0.74	0.22	0.19	0.46	2.07
37-48	0.73	0.16	0.15	0.27	1.64
49-60	0.84	0.14	0.12	0.12	0.86
Above 60	0.71	0.09			
MEAN LIFE EXPECTANCY					1.99

c. Year 2005

Age class(months)	Survival rate L	Survival l_x	L_x	T_x	Life expectancy e_x
0-3	0.53	0.53	0.45	1.52	2.86
4-12	0.72	0.38	0.33	1.06	2.78
13-24	0.76	0.29	0.25	0.73	2.5
25-36	0.76	0.22	0.19	0.47	2.14
37-48	0.77	0.17	0.15	0.28	1.62
49-60	0.81	0.14	0.12	0.12	0.89
Above 60	0.79	0.1			
MEAN LIFE EXPECTANCY					2.1

Table 5. 3: Life table for dog population in Loliondo game controlled area.

a. Year 2003

Age class (Months)	survival rate l	Survival l_x	L_x	T_x	Life expectancy e_x
0-3	0.667	0.667	0.621	2.884	4.3
4-12	0.864	0.576	0.550	2.262	3.9
13-24	0.909	0.523	0.499	1.712	3.3
25-36	0.908	0.476	0.449	1.212	2.5
37-48	0.887	0.422	0.389	0.764	1.8
49-60	0.886	0.374	0.366	0.366	0.9
Above 60	0.957	0.358			
MEAN LIFE EXPECTANCY					2.8

b. Year 2004

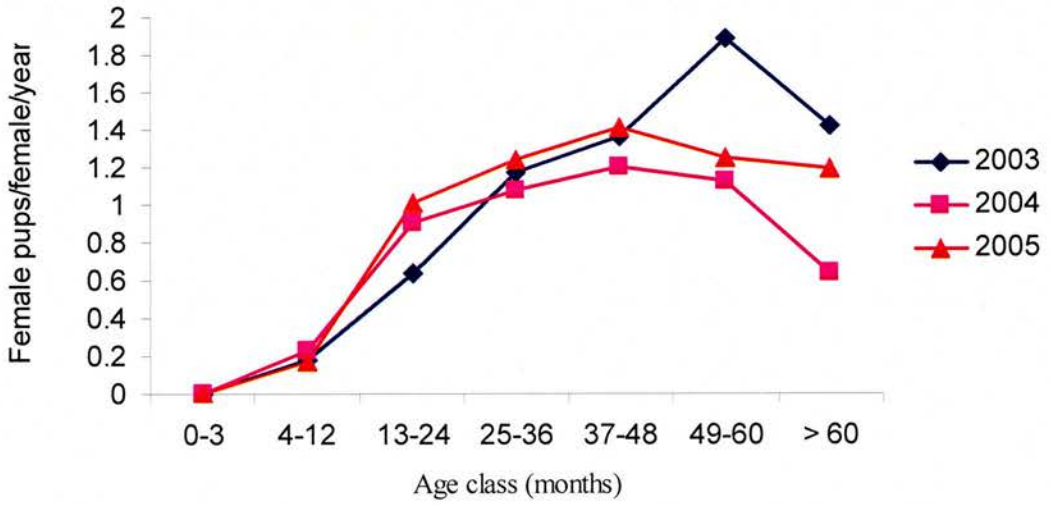
Age class (Months)	survival rate l	Survival l_x	L_x	T_x	Life expectancy e_x
0-3	0.611	0.611	0.621	2.884	4.6
4-12	0.904	0.552	0.550	2.262	3.9
13-24	0.954	0.527	0.499	1.712	3.2
25-36	0.905	0.477	0.449	1.212	2.4
37-48	0.857	0.409	0.389	0.764	1.7
49-60	0.864	0.353	0.366	0.366	0.9
Above 60	0.895	0.316			
MEAN LIFE EXPECTANCY					2.8

5.3.7. Age specific fecundity

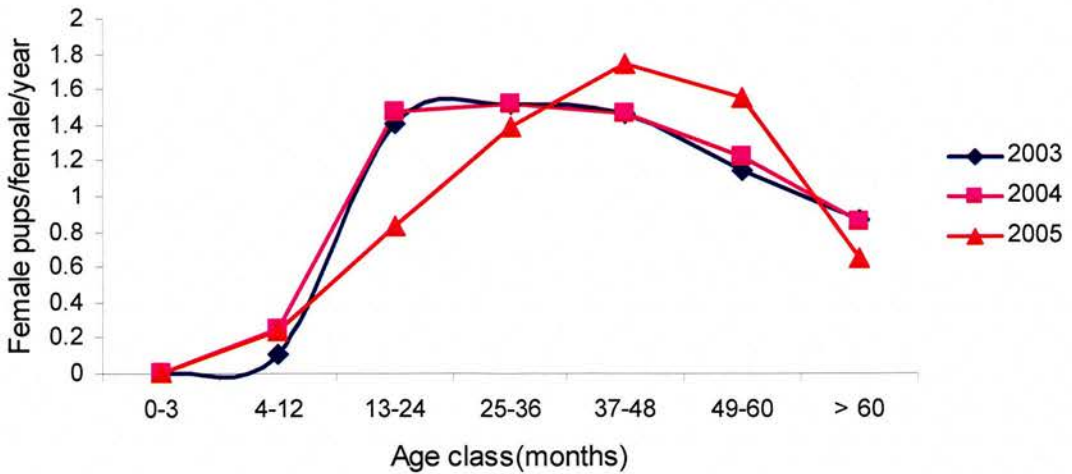
Overall fecundity schedules were comparatively stable between year 2003 and 2004 across the vaccination zone. Dogs aged between 3 to 5 years showed peaked fecundity with average mean litter size of 1.7 for the control zone, 1.2 for the agro-pastoral vaccination zone and 1.5 for the pastoral Loliondo Game Controlled Area

Figure 5. 12: Age specific fecundity rates determined from the household questionnaire survey

a. Agro-pastoral vaccination zone



b. Agro pastoral control zone



c. Pastoral Loliondo Game Controlled Area

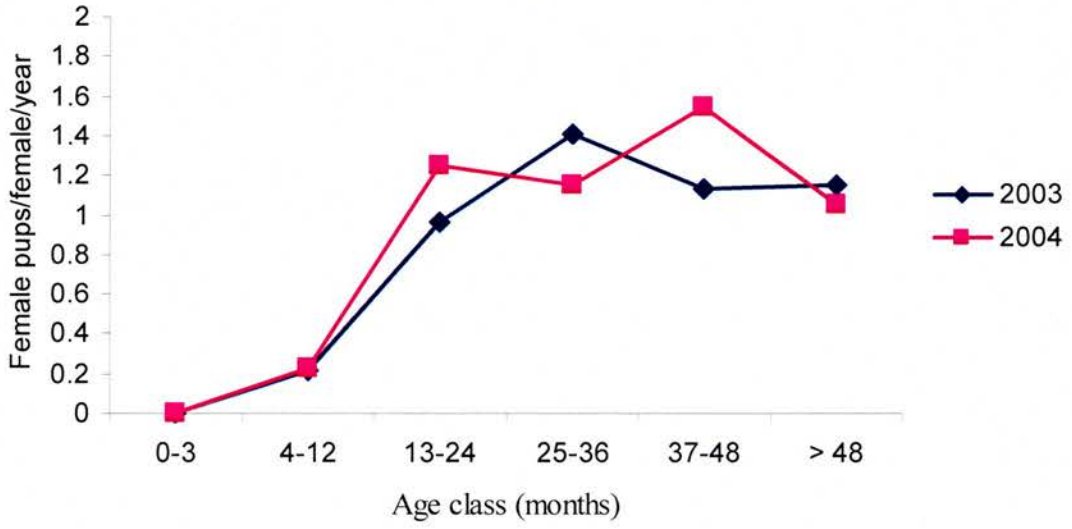


Table 5. 4: Fecundity schedules determined from household questionnaire survey

a. Vaccination zone 2003

Age class (months)	Number of females	Number of litter	Mean litter size	Number of puppies	Female births/female/year
0-3	146	0	0	0	0
4-12	180	16	4.13	0.37	0.18
13-24	167	48	4.44	1.28	0.64
25-36	89	45	4.62	2.34	1.17
37-48	29	18	4.39	2.72	1.36
48-60	18	16	4.25	3.78	1.89
Above 60	18	10	5.1	2.83	1.42

b. Vaccination zone 2004

Age class(months)	Number of females	No. of litters	Mean litter size	Number of puppies	Female births/female/year
0-3	399	0	0	0	0
4-12	276	30	4.13	0.45	0.22
13-24	257	141	3.6	1.8	0.9
25-36	203	131	4.31	2.16	1.08
37-48	86	50	4.8	2.4	1.2
49-60	42	18	4.5	2.25	1.13
Above 60	39	48	2.56	1.28	0.64

c. Vaccination zone 2005

Age class (months)	Number of females	Number of litters	Mean litter size	Number of puppies	Female births/female/year
0-3	115	0	0	0	0
4-12	159	13	4.15	0.34	0.17
13-24	161	76	4.26	2.01	1.01
25-36	123	69	4.41	2.47	1.24
37-48	68	45	4.26	2.82	1.41
49-60	37	21	4.38	2.48	1.24
Above 60	26	18	3.44	2.38	1.19

d. Loliondo game controlled area 2003

Age class (Months)	Number of females	No. of litters	Mean litter size	Number of pups	Female births/female/year
0-3	36	0	0	0	0
4-12	84	7	5.14	0.43	0.21
13-24	61	33	3.85	1.92	0.96
25-36	36	23	5.65	2.83	1.41
37-48	20	17	4.53	2.26	1.13
49-60	11	5	6.6	3.3	1.65
Above60	7	3	1.33	0.67	0.33

e. Loliondo game controlled area 2004

Age class (Months)	Number of females	No. of litters	Mean litter size	Number of pups	Female births/female/year
0-3	58	0	0	0	0
4-12	40	5	3.6	0.45	0.23
13-24	18	12	5	2.5	1.25
25-36	26	20	4.6	2.3	1.15
37-48	11	10	6.2	3.1	1.55
Above 48	10	10	4.2	2.1	1.05

f. Control zone 2003

Age class(months)	Number of females	Number of litters	Mean litter size	Number of puppies	Female births/female/year
0-3	48	0	0	0	0
3-12	104	4	5.75	0.22	0.11
13-24	54	27	5.63	2.81	1.41
25-36	42	32	3.97	3.02	1.51
37-48	24	17	4.3	2.92	1.46
49-60	42	21	3.52	2.28	1.14
Above 60	14	5	4.8	1.71	0.86

g. Control zone 2004

Age class(months)	Number of females	Number of litters	Mean litter size	Number of puppies	Female births/female/year
0-3	51	0	0	0	0
3-12	94	4	5.75	0.24	0.24
13-24	68	45	4.47	2.91	1.48
25-36	42	32	3.97	3.02	1.51
37-48	25	17	4.29	2.92	1.46
49-60	23	13	4.31	2.43	1.22
Above 60	20	9	3.78	1.70	0.85

h. Control zone

Age class (months)	Number of females	Number of litters	Mean litter size	Number of puppies	Female births per female
0-3	77	0	0	0	0
4-12	106	15	3.33	0.47	0.23
13-24	88	39	3.74	1.66	0.83
25-36	57	43	3.67	2.77	1.38
37-48	29	24	4.21	3.48	1.74
49-60	20	16	3.87	3.1	1.55
above 60	30	16	2.44	1.3	0.65

5.3.8. Dog population growth rate

The dog-to-human ratio and dog-to-household ratio for the agro-pastoral vaccination and control zones and the pastoral Loliondo Game Controlled are summarized in Table 5.8 reflecting an overall increase in dog population in year 2004. Overall the dog population in the vaccination zone was growing faster than the in the adjacent control zone dog population. However second year data indicates a decline in growth rate within the vaccination zone, while in the control zone the growth rate was higher in the second and third years of the study. Within the Loliondo game controlled area the post-vaccination growth rate was higher compared with the pre-vaccination growth rate. The intrinsic rate of increase and finite rate of increase for the vaccination zone, control zone and Loliondo game controlled area summarized in Table 5.7 and the intrinsic rate of increase plotted in Figure 5.10. In order to stabilise the growth of dog population in year 2004 within the vaccination zone, 60% of breeding female dogs need to be sterilized or prevented from breeding by other means such as hormonal contraception.

Figure 5. 13: Dog population growth within the vaccination and control zone and in the LGCA estimated using the Leslie matrix model

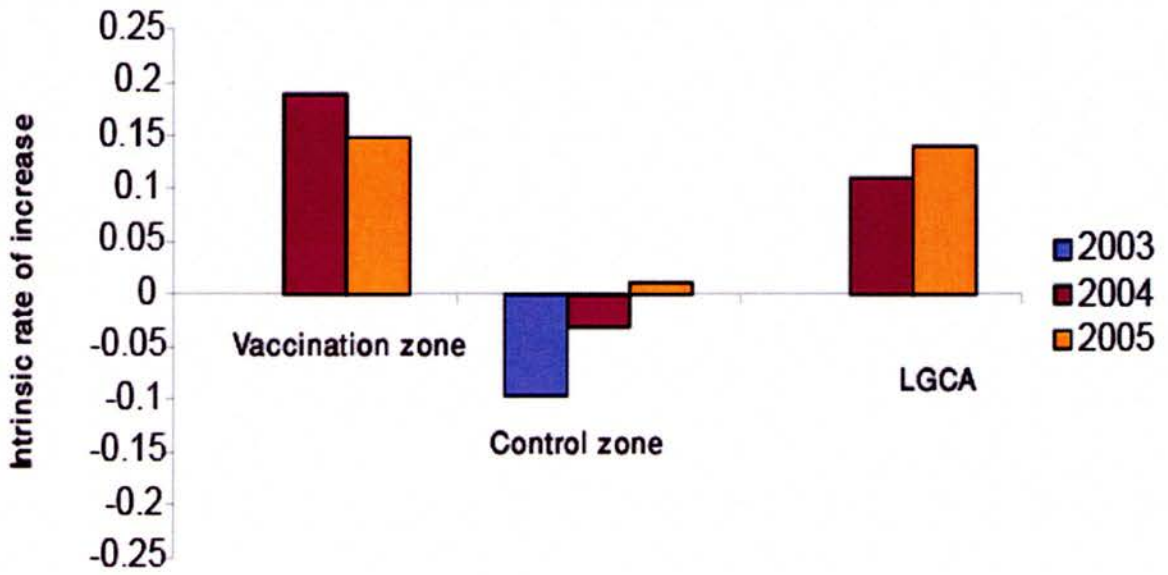


Table 5. 5: Intrinsic and finite rates of increase determined using Leslie matrix models

Vaccination zone		
Year	Intrinsic rate of increase (r)	Finite rate of increase (λ)
2004	0.189	1.2
2005	0.148	1.16
Control zone		
2003	-0.096	0.93
2004	-0.031	0.97
2005	0.011	1.011
Loliondo game controlled area		
2003	0.11	1.12
2004	0.14	1.15

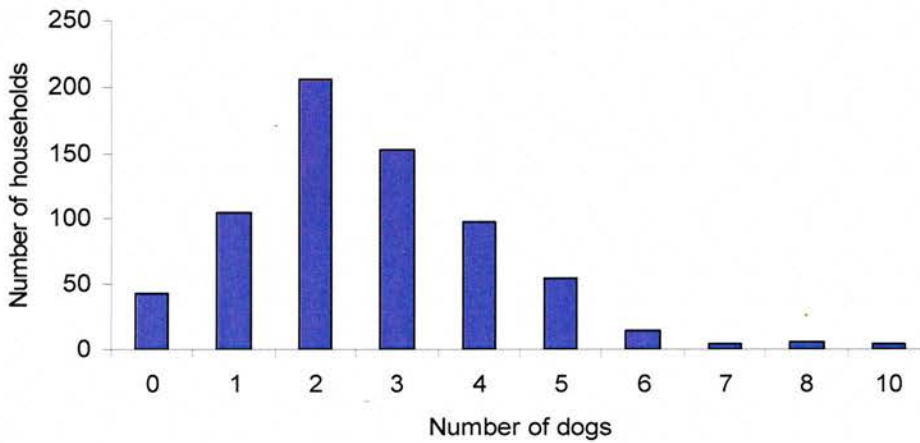
Table 5. 6: Dog human ratio estimated from household questionnaire survey

Vaccination zone					
Year	Number of households	Number of people	Number of dogs	Household- to- Dog ratio	Dog-to-human ratio
2003	1,444	11,598	1,597	1:1.2(1-1.4)	1:7.3 (6.3-8.3)
2004	1,238	10,593	1,880	1:1.6(1.4-1.9)	1:5.8(4.9-7.3)
2005	1,017	9,159	1,785	1:1.8 (1.6-2.1)	1:5.3 (4.7-6.6)
Control zone					
2003	859	6,489	975	1:1.2 (0.9-1.3)	1:8 (6.3-9.9)
2004	843	6,439	937	1:1.5 (1.3-1.8)	1:7.9 (6.6-10.3)
2005	673	5,664	1,036	1:1.2(0.9-1.4)	1:5.9 (5.1-7.3)
Loliondo Game Controlled Area					
2004	286	4,060	521	1:22 (1.2-3.8)	1:10.3 (7.9-13.7)
2005	195	1,872	447	1:2.3 (1.8-2.7)	1:4.55 (3.6-5.8)

5.3.9. Community dog population control measures

The optimal number of dogs that a household can keep varied according to the multiple roles of dogs in a community. On average a household interviewed indicated that they would keep 2.6 dogs (95% CI 2.5-2.74). Roles of dog included household and livestock security and helping out with livestock grazing.

Figure 5. 14: Frequency distribution of households indicating the maximum number of dogs a household is willing to keep as reported in household questionnaire survey



The number of dogs kept was demand driven with 97.2% (95% CI 95.66 – 98.26) of the households indicating that they would not keep dogs beyond their requirements. New born puppies were described as the major age class targeted for controlling the excess number of dogs in a household. Although households were not implementing population control measures at the time of this study, out of 705 households interviewed the following responses were reported to the question of dog control: 38.8 % (95% CI, 35.2-42.6) reported they would kill extra newborn puppies if they fail to give them away; 25.4% (95% CI 22.2- 28.7) expressed unwillingness to kill puppies and indicated that dogs are in high demand, giving away newborn puppies would not be problem; 20%(95% CI, 17-23) said if they do not find a place to give away newborn puppies, they would keep them regardless of whether are in excess of their demand; 6.2% (95% CI 4.6-8.3) said they would never keep female dogs in order to avoid having puppies and 9.9%(95% CI 7.82-12.4) had no idea about how to control excess puppies.

5.4. Discussion

This study demonstrates a significant increase in survival rate and dog population growth in vaccinated dogs within the vaccination zone in comparison with unvaccinated (control) dog populations in adjacent areas. The increase in survivorship is likely to be a result of the effect of herd immunity due to the multivalent vaccine imparted on the vaccination zone dog population. However, since the study involved the use of a multivalent vaccine, therefore, it is not possible to attribute the cause the cause of increased survival observed in the dog population after the vaccination. The increased survival in dogs could be due to reduced mortality due to rabies, but it is also likely the vaccine protected dogs against deaths due to canine parvovirus, distemper and hepatitis. As epidemiological data is not available on the prevalence and incidence of these infections in dogs in the study area, it is not possible to further speculate on the relative protection provided by different antigens contained in the vaccine.

However, the increase in growth rate within the vaccination zone observed in year 2003 was not sustained in the subsequent year with the intrinsic rate of increase declining by over 4% whereas within the control zone there was a relative increase in population growth in the subsequent years of the study. In the Loliondo game controlled area there was a slight post-vaccination increase in population growth. The observed dog population growth rate in the three zones is likely to depend largely on several factors including: i) the impact of the vaccination intervention ii) the health status of dog population iii) community demand for new dogs.

The second year decline in growth rate observed within the vaccination zone is likely to be a result of deliberate attempts by dog owners to regulate the number of dogs following the previous year's increase in dog population. On the other hand the relative increase in growth rate in the control zone for two subsequent years is likely to be attributable to attempts by dog owner to acquire more dogs to compensate for the negative population growth within the control zone. The increase in post vaccination growth rate within the Loliondo game controlled area is likely to be a result of vaccination intervention.

Overall the findings of this study demonstrated the likely importance of anthropogenic rather than ecological factors as the likely overriding regulator of dog population growth rate in the study area. However, the increase in dog population as a result of dog vaccination is likely to be only a transient phenomenon with dog owners implementing implicit population control measures in subsequent years with a view to bring down the dog population.

Pups were the age class which exhibited the most variable survival rate compared with other age classes. The 4% growth rate decline observed in the vaccination zone dog population for year 2005 was largely a result of decline in pup's survivorship, highlighting the potential role of pups as the important age class for regulating dog population growth in the study area. One possible hypothesis that can explain the decline in pup survival rate is owners increased neglect of dogs as a result of previous year's increase in dog population growth. The number of dogs that a household can keep is demand driven depending on the various requirements of dog

owners. When the demand is met, excess dogs are likely to be neglected through various means such as improper feeding or be abandoned. Pups are the age class which is likely to succumb more to the consequences of neglect compared with other age classes. With increased neglect, pups are likely to be more vulnerable to increase mortality rates through disease, starvation or become more prone to being preyed on by hyenas, a wildlife species which is an important domestic dog predator around the Serengeti ecosystem (Kaare pers. Obsv). However, despite the decline in growth rate in year 2005 within the vaccination zone, the dog population was still growing at a much higher rate than that observed in previous studies by Cleaveland (1996).

In previous vaccination campaigns canine distemper epidemics accompanied by high mortality has been observed in several villages within the study area specifically occurring following central point rabies vaccination programmes (M.Kaare, pers.obs). Mortality in dogs following rabies vaccination is likely to make the vaccination programme unpopular within communities and hence causing dog owner's hostility for future dog vaccination programmes. The inclusion of CVD and CPV vaccines in this study was specifically intended to prevent post-vaccination mortalities in dogs due to these viruses. Post vaccination mortalities would have incited public hostility as experienced in previous vaccination campaigns. Public doubts and resistance against vaccination are some of the key issues which are now assuming notable profile in medical vaccination programmes (Streefland, 2001). Inclusion of parvovirus, hepatitis and canine distemper in rabies vaccination is likely to have a positive community relations impact.

The dog population age distribution demonstrates that young dogs less than or equal to one year old form up to 48.4% of the population. The high proportion of young dogs in the dog population has important implications for the design of dog vaccination campaigns a subject which is discussed in a later chapter. There was a predominance of male dogs in all age classes of the population. Generally more dog owner in this study preferred to keep male dogs than female. The male preference is likely to be associated with the belief among dog owners that males are likely to perform better as guard dogs than females. In addition some owners do not keep female dogs because they do not want to raise puppies in their households, highlighting the existence of implicit population control measures within the community. Dog population mean life expectancy in both the agro-pastoral vaccination and control zone and within the Loliondo Game Controlled Area was short and consistent with that observed in the developing world dog populations (Cleaveland, 1996; Kitala et al., 2001; Brooks, 1990)

In some countries a combination of animal birth control measures and vaccination of neighbourhood dogs has been reported to have resulted into significant reductions in unsupervised dog numbers, human bite injuries and rabies cases (World Health Organization, 2004; Reece & Chawla, 2006). Except for the study in India by Reece & Chawla (2006) which attempted to correlate sterilization programmes and rabies incidence in human, none of the other birth control measures seem to be based on a detailed evaluation of their impact as effective approaches for rabies control. In addition none of the birth control measures has ever attempted to estimate the

proportion of female dogs that need to be sterilized in order to stabilize the dog population growth. The present study shows that in rural Tanzania where rabies vaccination is conducted, 60% of the breeding female dogs will need to be sterilized in order to maintain a demographically stable and immunized dog population. The proportion of breeding dogs to be sterilized is likely to require an intensive resource investment in terms of labour and finance highlighting the need for a detailed cost-effectiveness analysis of the strategy.

**Chapter VI: The Impact of mass dog vaccination on incidence of human bites
from suspected rabid animals and incidence of animal rabies**

6.0. Introduction

In much of the developing world, where dogs are not routinely vaccinated, incidence of rabies is known to be on the increase and the disease has been identified as a growing problem (Cleaveland, 1998; Perry, 1993) with human rabies due to dog bites being far more important than rabies due to other vectors such as wildlife. In these areas vaccination of domestic dogs against rabies is to date the known most effective way to reduce incidence of the disease in domestic animals, wildlife and human (World Health Organization, 2004). Advances in rabies vaccine technology and increased knowledge on control approaches over the past years have brought real hopes that vaccination of domestic dogs in the developing world will lead to marked reduction in human incidence of the disease. The successful reduction in the incidence of rabies in domestic animals and human in north America and western Europe was largely due to the elimination of canine rabies through vaccination (Krebs *et al.*, 2005; Bourhy *et al.*, 2005). A number of vaccination campaigns against rabies in various developing world countries have been implemented over the past 30 years with varying degrees of success. However, very few studies have attempted to correlate vaccination of domestic dogs with rabies incidence in human and animals. Most studies have focused mainly on vaccination coverage levels achieved. In some urban area of Korea for example a vaccination campaign that achieved coverage level of 30-50% was able to result into a significant reduction in animal and human rabies incidence (Lee *et al.*, 2001). In rural Tanzania vaccination campaign in domestic dogs over four consecutive years which attained coverage level between 60-80% resulted into up to 90% decline in incidence of both animal and human

rabies. The campaign in rural Tanzania also led to substantial reduction in the demand for PEP (Cleaveland *et al.*, 2003). In Brazil a synchronized vaccination campaign implemented over a five years period resulted in progressive decrease in incidence of animal and human rabies (Belloto, 1988) and more recently a significant decline in animal and human rabies has reported in central and southern America following a large scale rabies elimination campaign based on domestic dog vaccination (Belotto *et al.*, 2005). In Hermisillo, an urban area of Mexico, on the other hand, coverage level between 56-80% failed to control rabies (Eng *et al.*, 1993). Clearly the critical coverage level for rabies control is likely to differ from setting to setting depending on density of the dog population. An important question for any domestic dog vaccination campaign will be to evaluate its effectiveness by assessing its impact on the incidence of the disease in both human and animals. To address this question a quantifiable measure for evaluating the impact of dog vaccination is needed. The incidence of the disease in animals and human provides a useful evaluation measure.

However, a critical factor that is likely to affect the evaluation of the impact of domestic dog vaccination on incidence of animal and human rabies is the availability of reliable and accurate human and animal rabies incidence data. In much of the developing world countries rabies remains a grossly under-reported disease (World Health Organization, 2004; Cleaveland *et al.*, 2002). Some of the key reasons that are likely to contribute to the wide spread gross under-reporting of the disease include the limited number of rabies diagnostic laboratories with most cases of human and animal rabies not undergoing laboratory confirmation, logistic and practical difficulties with retrieval of diagnostic samples from animals, cases of

clinical rabies may be recorded locally but are not transmitted to central authorities and patients with clinical rabies may stay at home or seek treatment from local healers. As a result, in order to overcome the under-reporting problem alternative rabies surveillance strategies have been used. In Tanzania and Kenya for instance community-based active surveillance has been shown to be a more rigorous rabies surveillance measure that allows more realistic quantification of rabies incidence (Kitala *et al.*, 2000; Cleaveland *et al.*, 2002)

Investigating the relationship between animal rabies incidence and PEP demand is important for various reasons including rabies epidemiological surveillance and evaluation of economic impact of canine rabies control programmes. A study that evaluated the impact of mass dog vaccination in rural Tanzania used the demand for PEP as an indicator of rabies incidence in human (Cleaveland *et al.*, 2003). The relationship between incidence of animal rabies and PEP demand is likely to differ between settings. In rural Tanzania for example a strong correlation between the demand for PEP and mass dog vaccination has been demonstrated (Cleaveland *et al.*, 2003) with the demand declining by over 90% within three years of domestic dog vaccination programme. Two separate studies in Thailand, on the other hand, failed to demonstrate a rapid decline in demand for PEP despite significant reduction of animal rabies incidence through successive domestic dog vaccination campaigns against rabies (Hemachudha, 2005; Kamoltham *et al.*, 2003) highlighting for the possibility of a complex relationship between decline in incidence of animal rabies and the demand for PEP. Studies in Poland (Figure 6.1) reported that although wildlife and domestic animal vaccination resulted in nine fold decrease in animal

rabies the decline did not result in the expected reduction in the demand for PEP (Sadkowska-Todys *et al.*, 2005). A study in Canada (Figure 6.2), a country where human rabies has been largely controlled, has reported that the rate of decline in animal rabies incidence was not necessarily associated with an immediate commensurate decline in demand for PEP (Nunan *et al.*, 2002). All these examples highlight the possibility of a complex relationship between decline in animal rabies incidence and the demand for PEP.

Figure 6. 1: Relationship between PEP and animal rabies in Poland (Source: Sadkowska-Toys *et al.*, 2005)

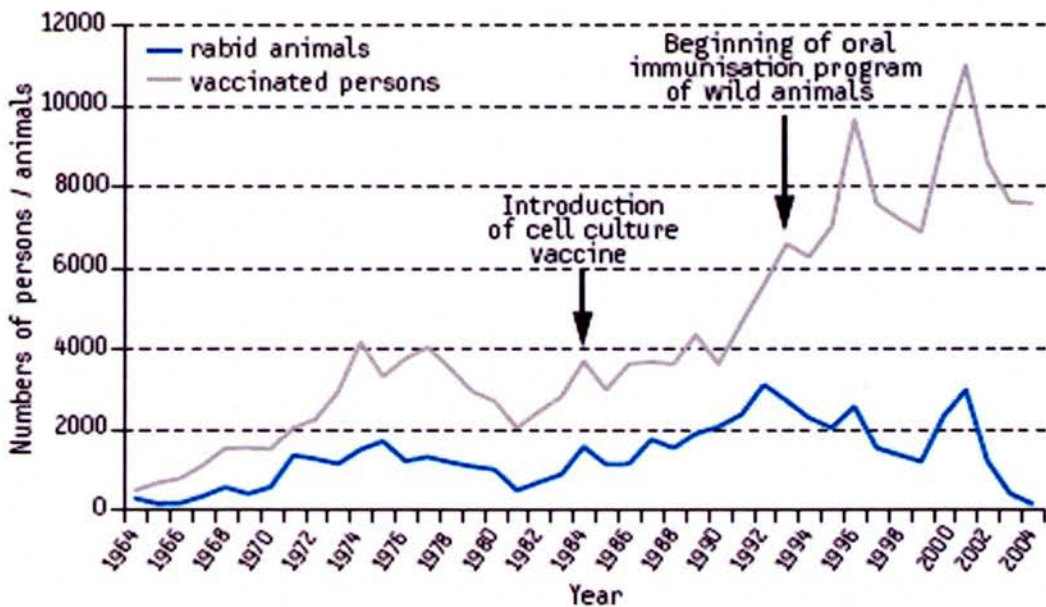
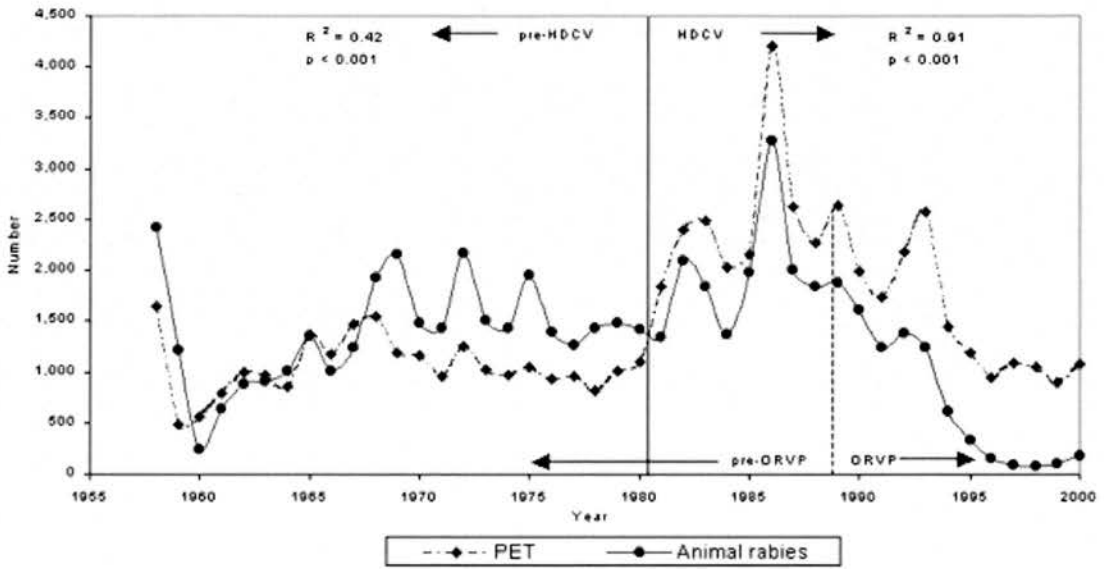


Figure 6. 2: Relationship between PEP and animal rabies in Ontario Canada (Source: Nunan *et al.*, 2002).



Control of rabies in domestic dogs is primarily intended to result in public health benefits through decreased incidence of the disease in human. Only few studies in the developing world have attempted to investigate and correlate domestic dog mass vaccination campaign with incidence of bites from suspected rabid dogs. In a small scale domestic dog vaccination campaign in rural Tanzania Cleaveland *et al.*, (2003) reported that the incidence of dog rabies and human bites from suspected rabid dogs was reduced by up to 92%. Decline in incidence of rabies following mass vaccination of dogs has also been reported in a few other studies (Belloto, 1988)

The aim of this study was to evaluate the impact of mass dog vaccination on incidence of animal rabies and human bites from suspected rabid dogs in the pastoral community setting located east of the Serengeti National Park and the multi-ethnic

agro-pastoral communities located west of the Park. Previous studies have reported that the human and dog population in the two settings differ significantly in demographic characteristics with the Maasai pastoral community characterized by lower human and dog densities than the agro-pastoral community.

6.1. Materials and methods

6.1.2. Study area

This study was conducted in the area described previously (Chapter II)

6.1.3. Evaluation of impact of dog vaccination on incidence of humans bitten by suspected rabid dogs

In order to evaluate the impact of dog vaccination on indicators of rabies incidence in both human and animals the study used two approaches: i) information on human bites from suspected rabid dogs obtained from district hospitals ii) data on animal and human rabies incidence collected from post-vaccination household questionnaire survey administered in the study villages.

Information was collected from district hospitals from all patients who presented at the hospitals with history of animal bite. Health officer at each district were specifically trained to fill in a dog bite report form which collected information from animal bite victim about the animal species which inflicted the bite and its ownership if it is a domestic animal, clinical signs manifested by the animal, whether the bite victim received wound first aid treatment, part of body bitten, severity of inflicted wound, if any other person or animal was bitten by the same animal and whether or not the animal was suspected to be rabid. The questionnaire used is included as Appendix IV. On the basis of the history presented, the clinical officers determined whether or not the bite victim was likely to have been due to rabid dog bite and hence recommend for PEP. These bites were classified here as suspect rabid dog bites. We use the hospital data on human bites from suspected rabid dog and the

demand for PEP to evaluate the impact of vaccination by comparing vaccination and post vaccination incidence of human bites from suspected rabid dogs and the demand for PEP.

To further explore the impact of vaccination on incidence of animal and human rabies, information was also collected from the post-vaccination household questionnaire survey described previously. Respondents were asked to describe if they have ever heard of any incidence of animal rabies in a village for the past one year and if there was any household member who had been bitten by a suspected rabid dog in the past one year. In the case of animal rabies, respondents were asked to describe as much as possible the clinical signs manifested by the animal and its fate, whereas for human bites from suspected rabid dogs respondents were asked to provide detailed information on animal species inflicting the bite, clinical signs shown by the biting animal, fate of biting animal and if the bite victims received any PEP. The data obtained from the number of household members bitten by suspected rabid dogs was used to estimate annual human bite incidence from suspected rabid dogs in the vaccination zone while that obtained from households regarding the reporting of any rabies case in a village was used as an index to evaluate the magnitude of human bites from suspected rabid dogs in a village. Data obtained from the vaccination zone questionnaire survey were compared with data collected from the control zone obtained using the same questionnaire.

6.1.4. Statistical analysis

Data on the number of humans treated at district hospitals as cases of bites from suspected rabid dogs were analysed using generalized linear models with Poisson errors. The number of humans treated was modelled as a response variable while the year of vaccination campaign and zone (control and vaccination zones) were included in the model as explanatory variables.

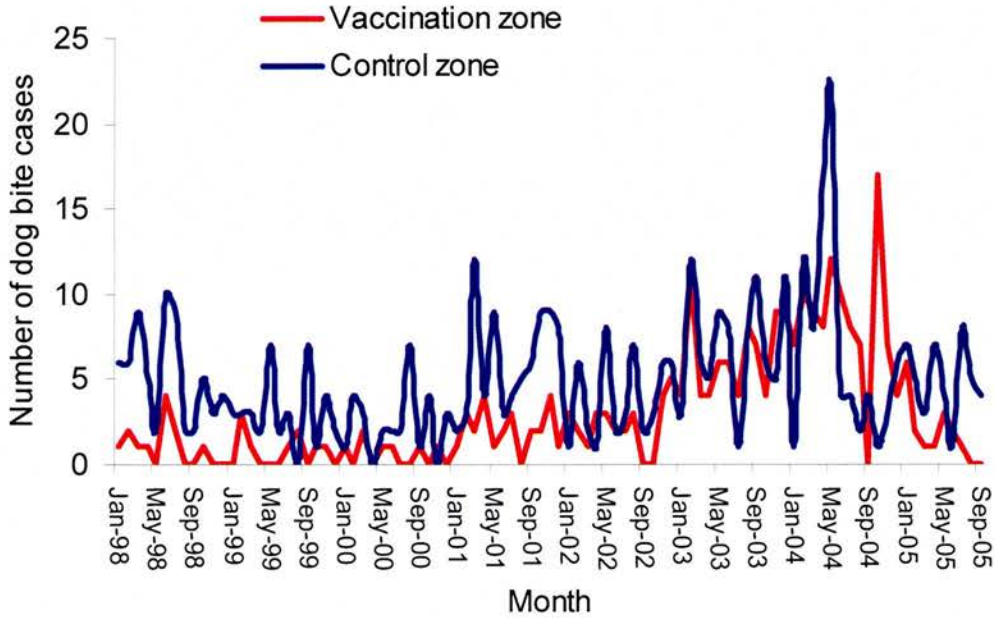
To investigate statistical difference in cases of animal rabies and number of humans bitten by suspected rabid dogs before and after the onset of the vaccination campaign within the vaccination zone data collected from household questionnaire survey was modelled using generalized linear model with Poisson errors. The number of human cases bitten by suspected rabid dogs and that of animal rabies cases reported were modelled as the response variables while the vaccination campaign year was included in the model as an explanatory variable. In order to investigate the difference in the number of households reporting hearing of news about animal rabies and humans bitten by suspected rabid dogs data collected from the questionnaire survey were similarly modelled using generalized linear model with Poisson errors with number of households reporting as the response variable and vaccination year as the explanatory variable. The difference in incidence of animal rabies cases was also investigated using generalized linear models with Poisson errors.

6.2. Results

6.2.2. Incidence of human bites from suspected rabid dogs

From January 1988 to September 2005 a total of 272 human bite cases from suspected rabid dogs were treated at district hospitals in the vaccination zone while the number of people treated in the control zone was 463 which is 1.7 higher than that treated in the vaccination zone. Within the vaccination zone alone an average of 2.2 human cases per month were treated at district hospital before the start of the vaccination campaign. The number of humans bitten by suspected rabid dogs and treated at district hospitals increased to 5.5 per month within 21 months after starting the vaccination campaign. The increase was 2.5 times more than the number of bite victims treated during the pre-vaccination period. Figure 6.3 show the monthly human bites from suspected rabid dogs treated at district hospitals in the vaccination and control zone from January 1998 to September 2005. Overall statistical analysis demonstrated a significant difference in the number of humans bitten by suspected rabid dogs who were treated at district hospitals. The number treated varied significantly between years ($\chi^2=82.34$, $df=1$ $p< 0.0001$) and between the control and vaccination zone ($\chi^2=50.21$, $df=1$, $p< 0.0001$). The number of humans treated at district hospitals as cases of bites by suspected rabid dogs (within the vaccination zone) 21 months after the onset of dog vaccination was also significantly higher than that reported before the implementation of dogs vaccination ($\chi^2=50.21$, $df=1$, $p< 0.0001$)

Figure 6. 3: Number of human bites from suspected rabid dogs treated at district hospitals in the control and vaccination zone from January 1998 to September 2005 based on PEP administration



The number of households that reported hearing cases of human bites from suspected rabid dogs and animal rabies cases within the past one year is illustrated Figures 6.4 to 6.6. Overall household reported news of fewer cases following the vaccination campaign. For human dog bite cases, 72 households in the vaccination zone reported hearing news of cases of humans bitten by suspected rabid dogs prior to start of vaccination campaign. A year after the campaign 36 households reported hearing cases of humans bitten by suspected rabid dogs, which is a reduction of 48.6% (95% CI 36.85-60.55). In comparison to the period before the onset of dog vaccination, the number of households reporting hearing cases of humans bitten by suspected rabid dogs was significantly lower one year after the implementation of the vaccination campaign ($\chi^2=64.35$, $df=1$, $p< 0.0001$). Similarly the number of households reporting

hearing news of animal rabies cases declined significantly ($\chi^2=296.05$, $df=1$, $p<0.0001$) following implementation of dog vaccination as illustrated in Figure 6.5. The comparison between the control and vaccination zones using post vaccination household questionnaire survey illustrated that 79 households reported hearing news of animal rabies cases within the vaccination zone while in the control zone 248 households reported hearing news of animal rabies cases. The total number of households that reported hearing news of animal rabies cases in the control zone was significantly higher than that in the vaccination zone ($\chi^2=91.72$, $df=1$, $p<0.0001$)

Figure 6. 4: Decline in number of households reporting hearing of humans bitten by suspected rabid animals following implementation of dog vaccination from year 2003 to 2005 as estimated from the post vaccination household questionnaire survey

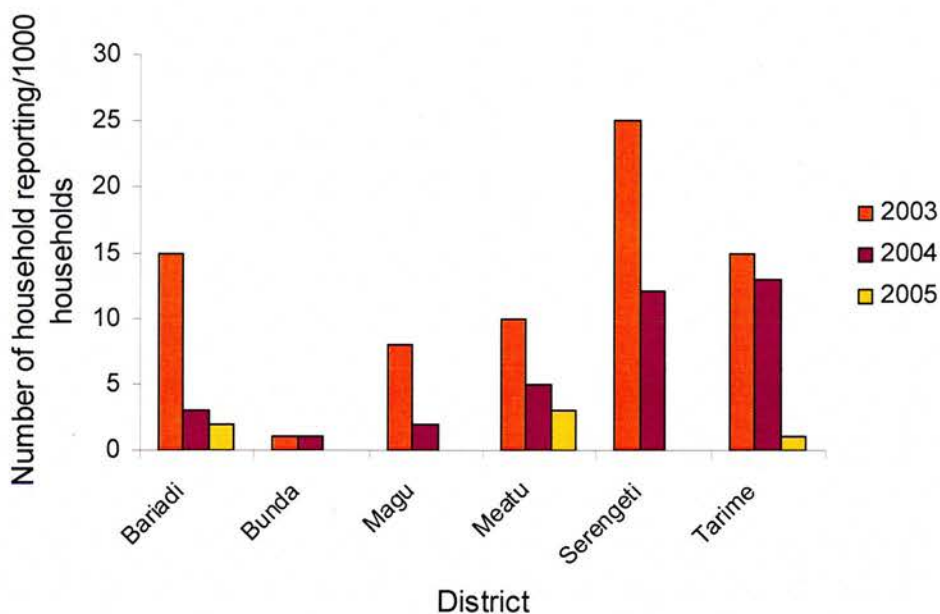


Figure 6. 5: Decline in number of households reporting hearing animal rabies cases following implementation of dog vaccination from year 2003 to 2005 as estimated from the post vaccination household questionnaire survey

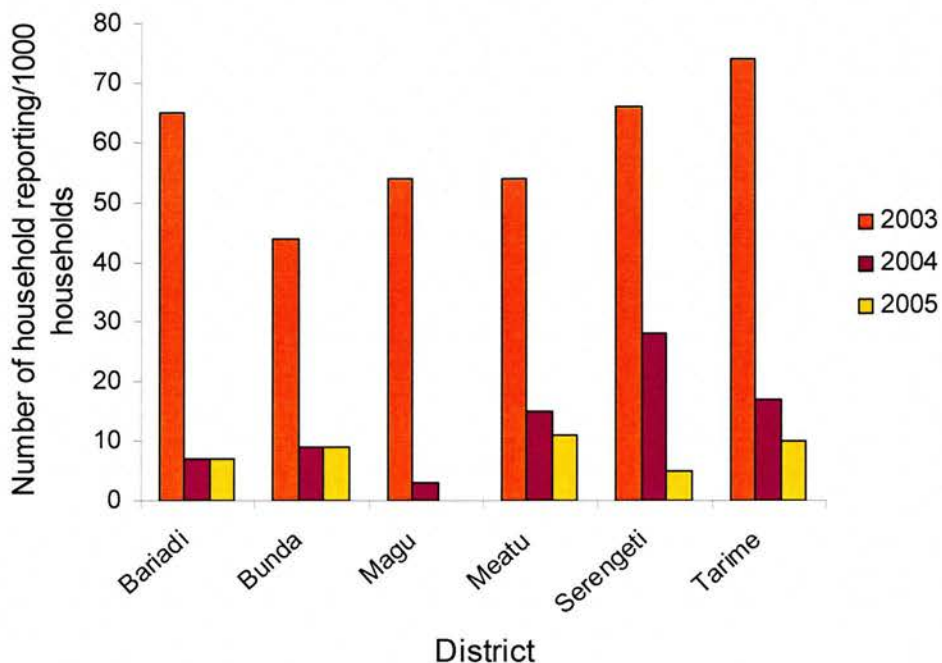
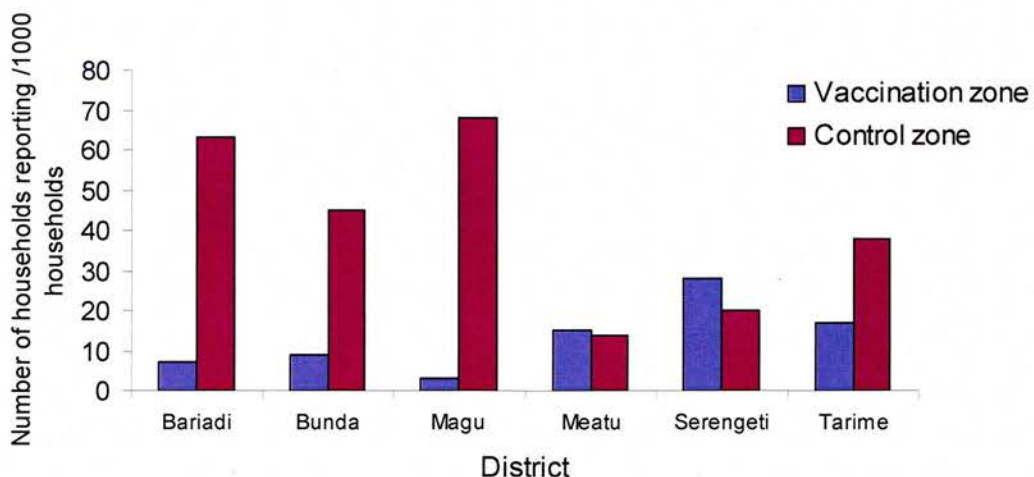


Figure 6. 6: Questionnaire survey data showing number of household reporting animal rabies in the vaccination and control zone after one year from onset of dog vaccination campaign



6.2.3. Incidence of animal rabies cases and cases of humans bitten by suspected rabid dogs

The incidence of suspected animal rabies reported from the household questionnaire survey decreased by 58.7% (95% CI 45.6-71) from year 2004 to year 2005 and the incidence of members of household bitten by suspected rabid dogs decreased by 84.3% (95% CI 71.4-93) within the same time frame. The number of animal rabies in year 2005 was significantly lower than that reported in year 2004 ($\chi^2=15.86$, $df=1$, $p< 0.0001$). Similarly the number of humans bitten by suspected rabid dogs was significantly lower in year 2005 in comparison with year 2004 ($\chi^2= 34.96$, $df=1$, $p< 0.0001$). Incidence of animal rabies and humans bitten by suspected rabid dogs reported from household questionnaire survey are illustrated in Figures 6.7 and 6.8.

Figure 6. 7: Incidence human bites from suspected rabid dogs within the vaccination zone estimated from number of member of household bitten by suspected rabid dogs in household questionnaire survey

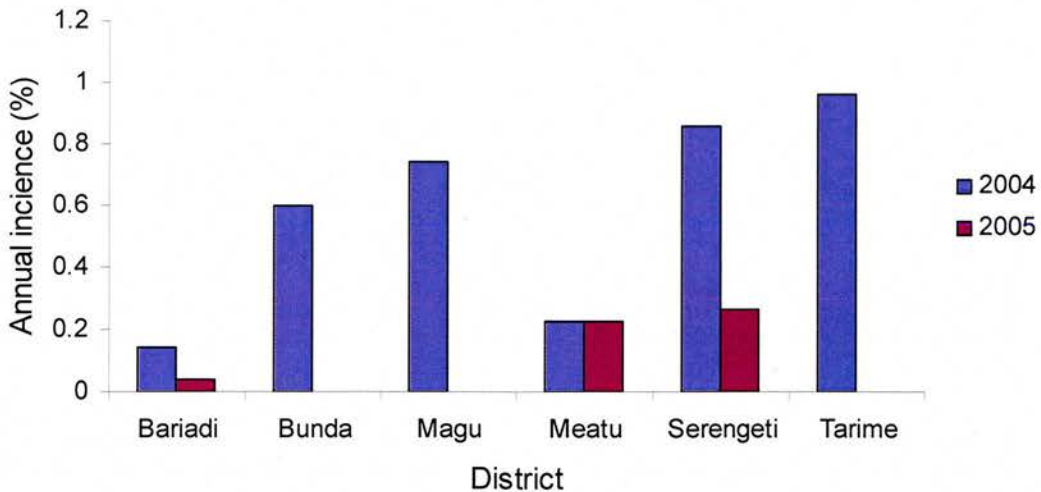
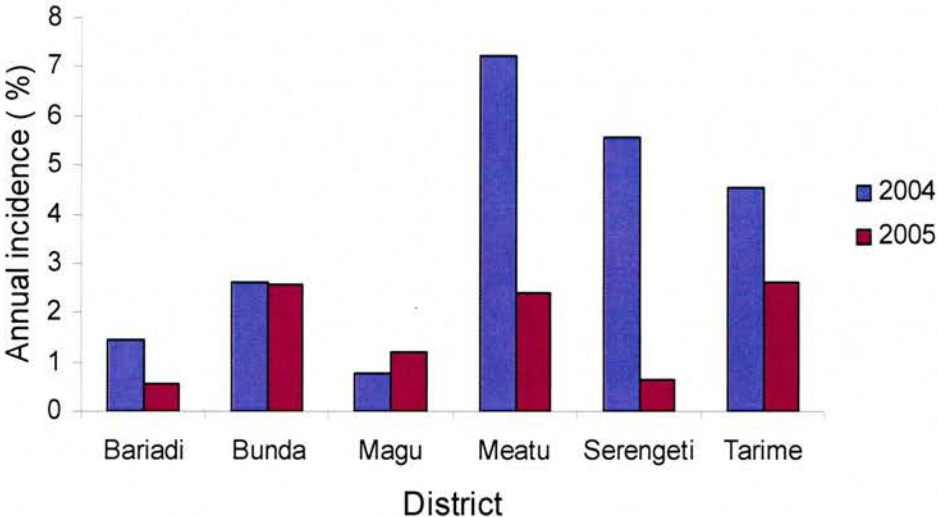


Figure 6. 8: Incidence of suspected animal rabies cases estimated from the household questionnaire survey within the vaccination zone



6.3. Discussion

This study demonstrates a significant decline in the incidence of both human and animal rabies cases following the onset of mass dog vaccination campaign in the study area. Overall the community reported less animal and human rabies cases after the implementation of the vaccination campaign compared to the period before the implementation of the vaccination campaign. Rabies incidence data from the household questionnaire survey indicate that the dog vaccination campaigns significantly reduced both animal and human rabies within the vaccination zone compared to the control zone. The data also demonstrates a significant post-vaccination reduction of the incidence of human bites from suspected rabid dogs within the vaccination zone itself before and after the implementation of dog mass vaccination programme. The finding of this study highlights the effectiveness of mass vaccination of domestic dogs as a key strategy for rabies control in both animal and human in the study area, Tanzania as a whole and other African country in general.

However the hospital passive surveillance data indicated an increase in the incidence of patients treated for bites from suspected rabid dogs. This study used PEP prescription by clinical officers as the key criterion for classifying patients as cases of bites from suspected rabid dogs. Studies in Thailand, Canada and Poland have demonstrated significant decrease in incidence of animal rabies incidence following canine vaccination against rabies but failed to demonstrated an immediate and commensurate parallel decline in the number of patients receiving PEP despite significant decrease in incidence of animal rabies (Kamoltham *et al.*, 2003;

Sadkowska-Todys *et al.*, 2005; Nunan *et al.*, 2002). In contrast, a dog vaccination campaign carried out in north-western Tanzania for four consecutive years resulted in successful control of domestic dog and human rabies with subsequent significant decline in the demand for PEP (Cleaveland *et al.*, 2003). Clearly the relationship between decline in animal rabies incidence and number of dog bite patients receiving PEP is likely to be varied and complex. One factor that is likely to have contributed to the decreased demand for PEP in the campaign by Cleaveland *et al.*, (2003) is the trust and confidence that the medical personnel and community had in the campaign's successfulness in controlling canine rabies and hence reducing the threat of rabies exposure from dog bites. For this to occur animal rabies need to be proven to be absent in a community for a considerable duration of time (Kaare pers.observ).

The demand for PEP is also likely to be influenced by the nature of collaboration between veterinary and medical sectors. For example the study by Cleaveland *et al.*, (2003) established a close collaboration between the veterinary and medical sectors in the study area and PEP was only prescribed subject to recommendations from the veterinary department concerning dog's rabies status, a factor which might have contributed significantly to reduced improper prescription of PEP (Cleaveland pers.com). However, under circumstances where it is not possible to confirm or rule out rabies exposure, optimal use PEP is likely to be a problematic issue. Although there has been no rigorous investigation as to the evaluation of the appropriate use of PEP in the developing world where most of this expensive resource is used, evidence of inappropriate use of PEP has been documented elsewhere. In some parts of the USA for example where rabies annual incidence is known to be very low up to 25%

of inappropriate use of PEP has been reported (Conti *et al.*, 2002). In some parts of Thailand, where rabies is known to be endemic, approximately 55% of patients treated after bites from suspected rabid dogs received PEP for animal bites that were not proven to be rabid (Swaddiwudhipong *et al.*, 1988). Although PEP remains a key component of human rabies prevention, its administration needs to be optimized and rationalized to avoid inappropriate use of this scarce and expensive public health resource. Clearly the appropriate use and demand for PEP is likely to be influenced by several factors. For example in rabies endemic areas the continuous presence of animal rabies accompanied by inadequate rabies diagnostic capacity PEP is likely to be administered as a precautionary measure even to patients that have not been exposed to the disease. Reliance on clinical diagnosis of rabies which is often based on bite-event history narration by dog bite victims is also likely to be an important factor contributing to inappropriate use of PEP in the developing world. A recent study in Turkey that has evaluated PEP practices demonstrated that PEP administration to patients was significantly associated with the place where the bite occurred (rural or urban), the age of bite victim, animal type and lack of vaccination certificates for a dog inflicting the bite (Kilic *et al.*, 2006). These criteria are likely to be used as a yardstick for PEP administration in most of the developing world including Tanzania. However despite their usefulness, these criteria are clearly subjective and are likely to depend largely on health personnel's perceptions of the presenting case, a phenomenon which is likely to contribute substantially to inappropriate use of PEP. The use of PEP is likely to be improved if there is an increased awareness and cooperation among professional people, health personnel and the community at large. In addition timely diagnosis of animal rabies cases is

also likely to contribute significantly to proper use of PEP. Currently the WHO advocates the direct fluorescent antibody test (DFAT) as the standard rabies diagnosis technique, however this techniques is expensive and requires expertise to carry out and interpret results (Dean *et al.*, 1996). Recently, relatively simple and less expensive rabies diagnosis tests such as the blot dot enzyme immunoassay and rapid immuno-histochemical test have been described and evaluated (Madhusudana *et al.*, 2004; Lembo *et al.*, 2006). These new techniques have substantial potential to be used as an alternative to the gold standard DFAT in the periphery veterinary facilities to provide more rapid and less expensive rabies diagnosis under the constraints of field conditions. The effective use of these rapid and less expensive diagnosis techniques is likely to result into substantial improvement in the optimization of the use of PEP. However, an interesting question for future studies would be to address the correlation between the incidence of animal rabies and demand for PEP particularly the time interval at which decline in animal rabies incidence will result in significant reduction in the demand for PEP as this is likely to be a critical factor not only for obtaining realistic rabies human bite passive surveillance data, but also for the economics of rabies control.

**Chapter VII: Optimal design of domestic dog rabies vaccination programmes
for rural Tanzania**

7.0. Introduction

Population wide mass vaccination programmes play a major role in the control and prevention of infectious disease of human and veterinary importance. One of the major outcomes of medical and veterinary science has been the success in eradication of some diseases by means of vaccination. In some parts of the world vaccination has been effective in controlling numerous human and animal infectious diseases such as measles, smallpox rubella, rinderpest, foot and mouth disease and the worldwide eradication of smallpox. Vaccination is therefore considered the primary and effective method of infectious disease control. The efficiency of mass vaccination is based on the principal of herd immunity which presupposes a collective impact of individuals vaccinated on the transmission of infection in a population whereby infection susceptibility and infectivity are reduced resulting in reduced probability of infection for individuals who are part of the vaccinated population regardless of their vaccination status (Anderson, 1992; Anderson & May, 1990; Anderson & May, 1985a; Anderson & May, 1985b; Anderson & May, 1982). This phenomenon is readily explained epidemiologically in terms of the basic reproductive number (R_0) which is defined as the number of secondary cases arising from a single primary case introduced into a completely susceptible population (Anderson & May 1991). Prevention of disease outbreaks through vaccination is achieved by reducing the density of susceptible (i.e. non-immune) host population sufficiently so that the effective basic reproduction number (R_v) in a vaccinated population falls below one. If $R_0 > 1$ each primary case will, on average, produce more than one secondary case and the infection will spread initially exponentially through

the population, leading to an epidemic. Conversely, when $R_0 < 1$ each primary case will, on average, produce less than one secondary case and, although some secondary cases may occur, the infection will tend to die out without a major epidemic (Woolhouse *et al.*, 1997).

In most of the developing world where public health resources are likely to be limited. A key issue that is likely to hinder effective control of infectious disease through mass vaccination is the lack of clear insight and understanding of how population wide mass vaccination programmes can be optimally designed and implemented to maximize the reduction of R_0 with the least vaccination effort. This usually involves understanding how to take advantage of low transmission heterogeneities, and mitigate most effectively against high transmission heterogeneities. Effective design and implementation of vaccination programmes requires a detailed understanding of the theoretical and empirical questions related to disease and infection epidemiology, ecology and demography of host populations, community socio-cultural factors, economics and organization of control strategies.

For human diseases theoretical aspects that are related to the design of vaccination programmes have been a subject of extensive review (Anderson & May 1991) but, as noted by Woolhouse *et al.*, (1997), less efforts have been devoted to investigating optimal design of veterinary vaccination programmes. Based on relative probability of exposure to infectious agents, theoretical studies for example have highlighted the importance of considering heterogeneities in host population in the design of optimal disease control programmes (Barbour, 1978; Hasibeder, 1986; Woolhouse *et al.*, 1997). For rabies control, epidemiological factors that influence the dynamics of

rabies infection, host population demography and socio-economic factors that influence accessibility of domestic dogs for parenteral vaccination are likely to play a critical role in the design and implementation of rabies vaccination programmes.

In order to devise effective strategies for controlling and preventing disease epidemics, it is essential to understand the underlying principles that affect the occurrence and spread of disease epidemics. Computer models provide a valuable tool in this field, since they allow, through simulations, the progress of a disease epidemic to be studied in a more controlled, detailed and repeatable way than would be possible in any real-life study (Filipe & Maule, 2004). Models for infectious diseases like the classical SIR model have proved useful in the theoretical estimation of the level of vaccination for control of directly transmitted diseases (Anderson & May, 1982; Anderson & May, 1985b; Anderson & May, 1985a; Anderson & May, 1986; Anderson, 1992).

Several computer based models have been used in predicting the spread of epidemics. Some of these models have investigated specific disease problems (Allen *et al.*, 2002; Kao, 2002), while others are designed for investigating the general principles involved in disease spread (Ball & Neal, 2002; Johansen, 1996). Although both are based on the same general epidemiological principles, they differ in the way each implement these principles. Some of these differences reflect the type of disease being modelled. In a model of a contagious human disease, for example, host individuals might be grouped together in households (Ball & Lyne, 2002), whereas in a model of an animal disease, the host population is likely to be structured differently. Other differences reflect alternative modelling strategies. Some models,

for example, use mathematical equations to track the fate of the population as a whole, while others treat host individuals as discrete units (Sirakoulis *et al.*, 2000). Even amongst models that are of a similar type, there may be considerable differences in the specific way in which the models are implemented (Filipe & Maule, 2004; Johansen, 1996; Rhodes & Anderson, 1997).

In nearly all epidemic models, a host population is divided into classes, such as 'susceptible', 'exposed', 'infectious', 'vaccinated' and 'recovered' (or removed). Individuals move between these classes according to the rules or equations that govern the behaviour of the model (Johansen, 1996). Models are commonly referred to according to the sequence in which a host moves through these classes. For example, an 'SIRS' model is one in which a Susceptible host acquires the disease, becomes immediately Infectious, subsequently enters a Recovered state in which it is immune to re-infection, and may finally become Susceptible again (Ball & Lyne, 2002).

Many studies have modelled epidemics by using differential equations to specify how the number of host individuals present in each class (susceptible, infected, etc) changes over time. However, although such models provide a simple theoretical framework for the understanding of disease spread, they fail to take into account important characteristics of real-life epidemics. Many simple models based on differential equations assume that a host population is homogenous and uniformly-mixing (Sirakoulis *et al.*, 2000); this assumption is not always true especially when modelling epidemics among organisms whose mobility is limited (Brown & Bolker, 2004). This is likely to apply to epidemics among animals that are sessile, territorial,

or enclosed on farms (Thomson & Ellner, 2003). Another shortfall of models based on differential equations is that they allow infectious agents to recover from very low prevalence levels at which they would naturally be almost certain to go extinct. This is because these models do not incorporate stochasticity, and they represent quantities such as the number of infected individuals as continuous variables rather than discrete units (Allen *et al.*, 2002; Lloyd, 2001). An additional disadvantage of the simplest models based upon mathematical equations is that they do not allow the study of spatial patterns in the spread of an epidemic.

These problems can be overcome by the use of spatially-explicit models in which host individuals are simulated as discrete entities occupying definite positions on a landscape. Such models may take the form of 'point process models' in which host individuals are located at points in continuous space (Brown & Bolker, 2004), or 'lattice models' (the simplest of which are also known as cellular automata) in which simulated host organisms occupy cells on a grid (Filipe & Maule, 2004). Although lattice models are usually considered less realistic than point process models, they are easier to compute and analyse (dos Santos *et al.*, 1998; Thomson & Ellner, 2003), and have been successfully applied to certain real-life epidemic situations, for example, rabies in foxes (Rhodes & Anderson, 1998).

One of the key aspects of an epidemiological model is the rule governing the spread of infection from one host to another. In a spatially-explicit model, disease transmission is more likely to occur between host individuals that are physically close to one another than between those that are far apart; the precise relationship

between the probability of disease transmission and the distance involved depends upon the situation being modelled. Many models deal with host individuals that occur in groups, such as human beings in households (Ball & Lyne, 2002; Ball & Lyne, 2002) or livestock on farms (Bouma *et al.*, 2003). Since patterns of contact between members of the same group will differ from the patterns of contact between individuals in different groups, such models often consider 'within-group' and 'between-group' transmission separately (Ball & Neal, 2002).

Some models distinguish in more general terms between short-range ('direct' or 'local') transmission occurring within a local neighbourhood, and long-range ('indirect' or 'global') transmission occurring uniformly within the entire population. For example, in 'great circle models', host individuals are arranged around a circle, and transmission can occur either locally between adjacent individuals along the circle, or globally across the circle to a random individual (Ball & Neal, 2002). Such models are closely related to models of human social networks in which individuals are connected by many local connections and a few long-distance ones (Ball & Lyne, 2002); these are known as 'small world networks' because two individuals on the network are generally connected by a relatively short chain of acquaintances (Zanette & Kuperman, 2002). Lattice models such as that of Johansen (1996), in which disease transmission can occur 'directly' between adjacent individuals or 'indirectly' between random individuals anywhere on the lattice, are essentially two-dimensional versions of the great circle model. Real-life scenarios for which such a model might be useful include animal diseases such as rabies that is more likely to spread locally

between neighbouring villages or carried over long distances by infected domestic dogs or wildlife species.

One of the most important practical applications of epidemic models is in predicting the impact of disease control measures (Rhodes & Anderson, 1997). The resources available to disease control programmes are often limited, and models can be used to deduce how best to deploy these in order to minimise the likelihood or severity of an epidemic (Ball & Lyne, 2002). Most such studies have concerned the impact of vaccination programmes, but similar modelling techniques could be applied to any form of disease control that reduces individuals' susceptibility to disease or removes them from the susceptible population. In addition to vaccination, such forms of control could include: prophylactic medication; isolation measures that reduce contact between individuals, as in the case of foot-and-mouth disease (Bouma *et al.*, 2003); culling of susceptible individuals, as in the case of fox rabies (Smith & Cheeseman, 2002); or health education schemes that reduce individuals' susceptibility to disease by modifying their behaviour, as in the case of many human diseases (Kribs-Zaleta & Velasco-Hernandez, 2000).

The population dynamics of infectious diseases are strongly influenced by the basic reproductive number R_0 (Chapter I). The value of R_0 for a given pathogen in a given host population is determined by a number of different factors including the transmissibility of infection, the period over which an infected host is infectious and the population density of hosts. The details of these relationships

depend on the mode of transmission (for example direct contact, vector borne, sexual contact) and are comprehensively discussed elsewhere (Anderson & May, 1991).

In this chapter, using a spatially explicit stochastic model the study explores possible future strategic and organizational options for the design of effective mass vaccination of domestic dogs in rural Tanzania. The model is used to investigate the impact of the following approaches on: i) the effectiveness of synchronized and asynchronous pulse domestic vaccination campaigns on incidence of rabies in domestic dogs; ii) the impact of continuous domestic dog vaccination; iii) the impact of dog population size heterogeneities in rabies control; and iv) the impact of inter-vaccination interval on the incidence of rabies in domestic dogs.

7.1. Materials and method

7.1.2. Model development

A model was developed to investigate the impact of two domestic dog vaccination strategies on incidence of rabies in domestic dogs i) pulse and ii) continuous vaccination. This allowed evaluation of three different strategies i) synchronized pulse vaccination ii) asynchronized pulse vaccination and iii) continuous vaccination. A spatially explicit demographically stochastic SIR model was developed by Dr. Daniel Haydon of Glasgow University in Borland Delphi and parameterized using data collected in Serengeti district dog population. The model was developed to reflect dog population demographic stochasticity based on data collected in this study and previous data collected in the Serengeti district by Cleaveland (1996). The dynamics of the model proceeds in a sequence of discrete rather than continuous events with individuals dogs dying from various causes including infection from rabies. The stochastic dynamics occurring in the model are shown in Figure 7.1. The variables and parameters of the model are as follows:

S = Number of susceptible individuals

I = Number of infected individuals

V = Number of vaccinated individuals

N = Population size = $S + I + V$

β = *Per capita* rate at which susceptible individuals acquire infection from infected individuals.

σ = Natural death rate

γ = Death rate due to rabies infection

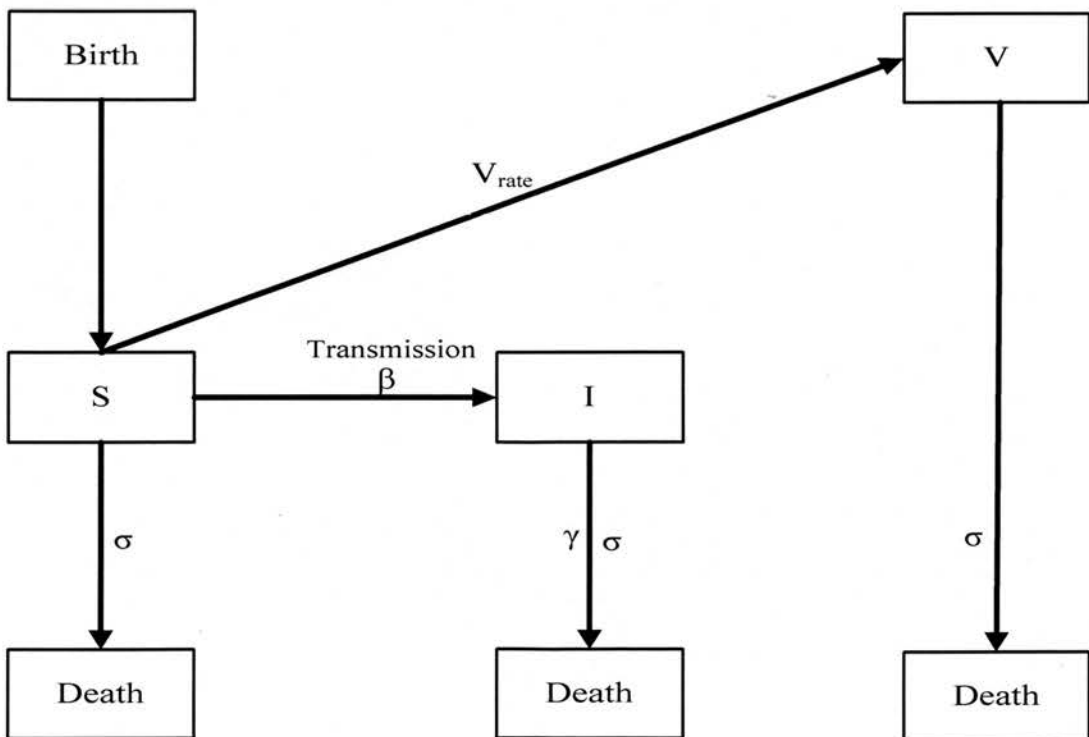
ε = Rate of infection from sources out-with the structure of the model

The model makes the following important assumptions:

- The population is closed and death and births rates are assumed to be equal so that the population size, N , remains approximately constant.
- However, infection is assumed to be introduced into this closed population at rates ε , as a result of immigration of infected dogs, or transmission from infected wildlife.
- All newborns become immediately susceptible
- Random contact between individuals with constant transmission rate β . The basic reproductive rate R_0 is assumed to scale positively with dog population size. However for villages with very high dog population sizes the value of R_0 becomes unrealistically high. The model mitigates the effect of largest villages by assuming 3 as the maximum value of R_0 . The decision to make 3 as the maximum value of R_0 was based on the findings of a parallel study in the area (Hampson, unpublished data). The model assumes a basic reproductive rate of 1.2 within villages and 1% of this to account for between villages transmission. The model also assumes that the value of the basic reproductive number is reduced by 75% within three days through implementation of various measures such as killing of suspected rabid dog and dog confinement.
- When a susceptible individual becomes infected, it immediately becomes an infectious individual, there is no latent period, then they either die from natural cause or due to infection with rabies virus
- Once an individual enters V they can not re-enter S or I

- The basic reproductive number R_0 is density dependent but asymptotes to 3 regardless of dog density
- Dogs that die are replaced immediately but for large intense epidemics it becomes unrealistic that dogs will be replaced immediately a fact which invalidates the use of the model for large intense epidemics
- Households and hence dog population is either distributed homogeneously with all the villages having the same population size or heterogeneously where the actual number of households and hence actual dog population were used.
- Contact radius for rabies transmission is assumed to be 5 km from the centre of each village beyond which no transmission is considered to occur.

Figure 7. 1: A simple compartmental diagram reflecting the population dynamics taking place in the model



At any given time the model assumes that individuals in the dog population are in one of the four states (S, I, V). Susceptible individual can become infected through contact by an infected individual from neighbouring villages located within a 5km radius or implicitly via a wildlife species from a neighbouring wildlife protected area. Once infected the S individual became infectious immediately, the model assumes no latent period for the disease. An infected individual cannot recover and will end up dying and removed from the population (assuming 100% case fatality rate). The model assumes that all individuals vaccinated become protected by the vaccine (100% vaccine take) and vaccine provides lifelong immunity (Domestic dog mean life expectancy is not more than three years and the vaccine provides three years protection against rabies).

The transmission parameter β depends on the probability that an encounter between a susceptible and infective dog results in rabies transmission and the rate at which such encounters occurs. Clearly this parameter could depend on the structure and size of the population because abundance of susceptible and infectious hosts is one of the important factors that influence the spread of a disease through a population. Theoretical models of host-pathogen systems usually assumes that transmission is a linear function of abundance (Anderson and May 1981, McCallum *et al.* 2001). In the current model the population is assumed to be closed with negligible temporal changes in dog population size. The model therefore assumes a constant *per capita* transmission rate. The dynamics of the population are summarized by the standard SIR differential equation as follows:

$$\frac{dS_i}{dt} = replacement - \sigma S_i - \sum_{j=1}^n \beta_{ij} S_i I_j$$

$$\frac{dI_i}{dt} = \varepsilon + \sum_{j=1}^n \beta_{ij} S_i I_j - \sigma I_i - YI_i$$

$$\frac{dR_i}{dt} = \sigma(I_i + S_i + V_i) + YI_i$$

$$\frac{dV_i}{dt} = V_{rate} - \sigma V_i$$

Parameters of the model which were kept constant are shown in Table 7.1. The model differential equations are integrated assuming a demographically stochastic process in which the probability of each class of individual in each village increasing or decreasing by an integer quantity is given by the following expressions:

$$\text{Prob}(S_i \rightarrow S_i + 1) = \text{replacement} / \text{Total rate}$$

$$\text{Prob}(S_i \rightarrow S_i - 1) = (\sigma S_i + \sum_{j=1}^n \beta_{ij} S_i I_j) / \text{Total rate}$$

$$\text{Prob}(I_i \rightarrow I_i + 1) = (\varepsilon + \sum_{j=1}^n \beta_{ij} S_i I_j) / \text{Total rate}$$

$$\text{Prob}(I_i \rightarrow I_i - 1) = (\sigma I_i + YI_i) / \text{Total rate}$$

$$\text{Prob}(R_i \rightarrow R_i + 1) = (\sigma(I_i + S_i + V_i) + YI_i) / \text{Total rate}$$

$$\text{Prob}(R_i \rightarrow R_i - 1) = 0$$

$$\text{Prob}(V_i \rightarrow V_i + 1) = V_{rate} / \text{Total rate}$$

$$\text{Prob}(V_i \rightarrow V_i - 1) = \sigma V_i / \text{Total rate}$$

$$\text{Where Total rate} = \text{replacement} + \sigma S_i + \sum_{j=1}^n \beta_{ij} S_i I_j$$

$$+ \varepsilon + \sum_{j=1}^n \beta_{ij} S_i I_j + \sigma I_i + YI_i$$

$$+ \sigma(I_i + S_i + V_i) + YI_i$$

$$+ V_{rate} + \sigma V_i$$

Table 7. 1: Model parameters that were kept constant through out the simulations

Parameter	Value
Death rate due to rabies	0.2
Mortality probability	1 (100% case fatality rate)
Background death rate	0.0011
Birth rate	0.1
Total number of months simulated	43,800 (120 years)
Random number seed	3
Run off period	7,300
Number of village	75
Contact radius	5 km
Basic reproductive number	1.2 with 75% forced reduction after 3 days
Disease re-introduction rate	0.05 per day

7.1.3. Spatial distribution of villages and dog recruitment

The model was parameterized using spatial and population and household census data from the National Bureau of Statistics for the 2002 Tanzania census. The GPS coordinates for each village in the district were used to spatially reference each village in the model. The number of households in a village was used to estimate the total village dog population size using the dog household ratio of 1:1 obtained in this study (Chapter V). Households and hence the dog populations in each village in the model were assumed to be distributed in two ways: i) homogenously where the average number of households was used and all villages were assumed to have the

same dog population and ii) heterogeneously where the actual number of households in each village and hence the actual rather than the average dog population.

The model assumes dogs that die for whatever reason are immediately replaced by owners. However for very high dog mortality rate it becomes unrealistic that such a large number of dogs will be replaced immediately, and so the model is not appropriate for the study of the dynamics of very large and intense outbreaks.

7.1.4. Vaccination coverage and inter-vaccination interval

For the homogeneously structured dog population the model tested the impact of varying inter-vaccination interval and vaccination coverage for both asynchronized and synchronized strategies at vaccination coverage ranging from 20% to 100% and four, six, eight, ten and twelve months inter-vaccination intervals. The model was run to produce rabies monthly incidence data for 1440 months with a 240 months run off period to dissipate transient incidence data and allow for output incidence data to stabilize. Incidence data for the first 240 months were therefore discarded and not included in the analysis.

7.1.5. Pulse vaccination:

For pulse vaccination the model assumes that a fraction of the entire susceptible population is vaccinated in a single pulse applied after every time interval T . Pulse vaccination is assumed to give lifelong immunity and all vaccinated dogs move to the "Vaccinated" class V of the population and once in the V class dogs can not move to the Susceptible or Infected classes in the model.

7.1.6. Asynchronized versus synchronized campaigns

The asynchronized campaign was modeled as being implemented on a different day for each village. With a total of 75 villages in the Serengeti district the asynchronized vaccination campaign was assumed to distribute the day that each village was vaccinated evenly over the course of a year. In contrast, the synchronized vaccination campaign was modeled as being implemented on a single day across the entire district.

7.1.7. The impact of patchy vaccination on rabies incidence

Vaccination coverage data from the 2003 campaign from 6 villages in Serengeti district were used to investigate the impact of patchy versus even vaccination coverage. The vaccination coverage in these villages varied within a uniform range of $60\% \pm 23$. For the even vaccination coverage the proportion of dogs vaccinated was assumed to be 60% for all villages whereas for the patchy coverage the proportion vaccinated was assumed to vary within the $60\% \pm 23$ range.

7.1.8. Continuous vaccination campaign

With the continuous vaccination campaign the model assumes that dog vaccination proceeds continuously in a village as new susceptible unvaccinated dogs appear either by birth or immigration. The continuous vaccination campaign was assumed to represent the CAHW vaccination strategy described in chapter IV. Rabies incidence data obtained from continuous vaccination simulations were compared with those obtained from asynchronized vaccination campaigns repeated after six months (six months inter-vaccination interval)

7.1.9. Impact of heterogeneously structured dog population on rabies incidence

In order to investigate the impact of heterogeneities in dog population size on number of rabies cases the model was run to simulate asynchronized vaccination campaigns with a homogeneously and heterogeneously structured dog population. Rabies incidence data from the simulations were compared to assess the impact of heterogeneously structured population on rabies incidence.

7.2. Results

7.2.2. Impact of pulse vaccination campaigns in a homogenously structured population

Figure 7.2 to 7.6 illustrate the impact of synchronized and asynchronized vaccination campaigns in a homogenously structured population at different inter-vaccination intervals and coverage levels. Overall the model predicted lower number of mean rabies cases per year with synchronized campaigns compared to asynchronized campaigns. The model results also demonstrate that shorter inter-vaccination intervals and higher vaccination coverage levels were most effective than longer intervals and lower coverage levels.

Figure 7. 2: Synchronized and asynchronized pulse vaccination campaigns repeated after every four month interval at vaccination coverage ranging from 20% to 100% in a homogenously structured population.

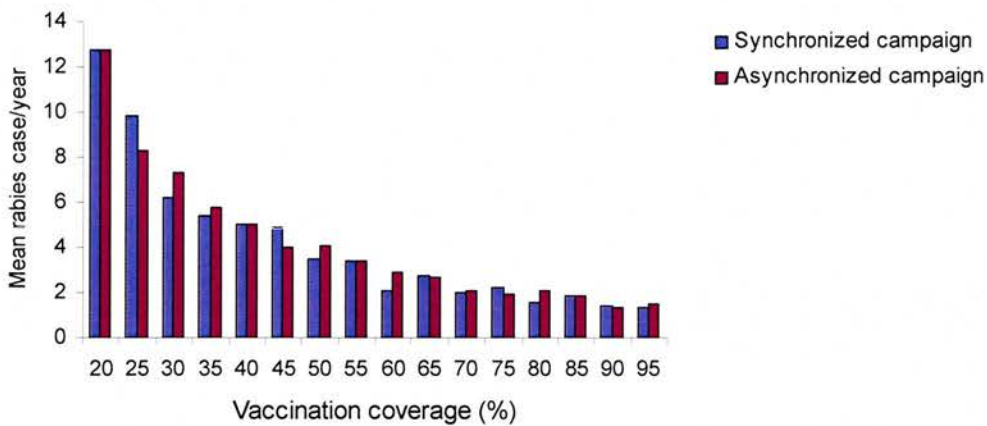


Figure 7. 3: Synchronized and asynchronous pulse vaccination campaigns repeated after every six month interval at vaccination coverage ranging from 20% to 100% in a homogenously structured population.

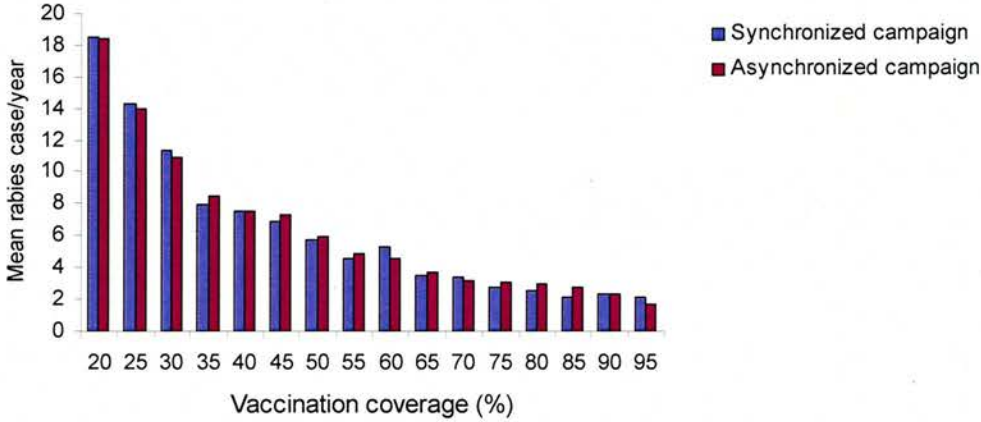


Figure 7. 4: Synchronized and asynchronous pulse vaccination campaigns repeated after every eight month interval at vaccination coverage ranging from 20% to 100% in a homogenously structured population.

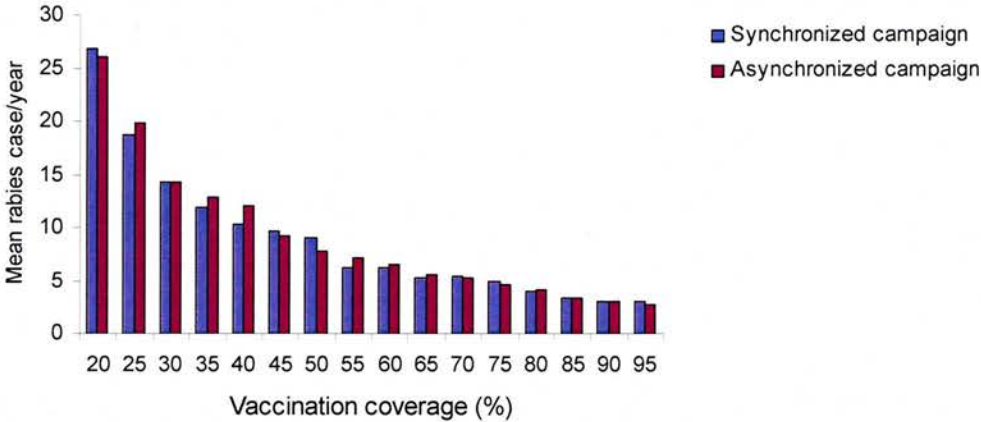


Figure 7. 5: Synchronized and asynchronous pulse vaccination campaigns repeated after every 10 month interval at vaccination coverage ranging from 20% to 100% in a homogenously structured population.

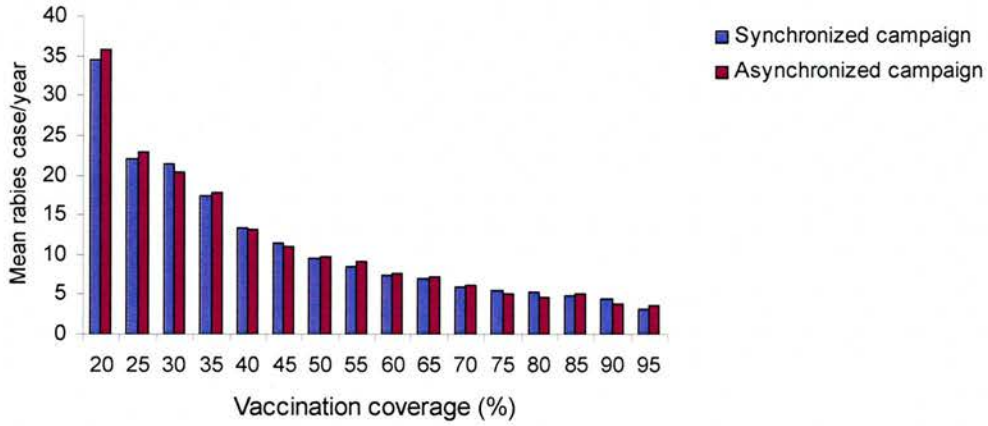
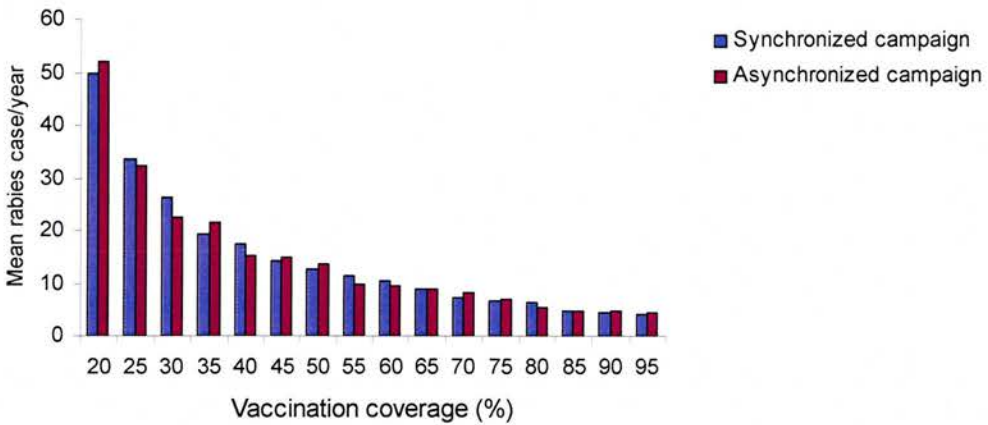


Figure 7. 6: Synchronized and asynchronous pulse vaccination campaigns repeated after every 12 month interval at vaccination coverage ranging from 20% to 100% in a homogenously structured population.



7.2.3. Comparison of the impact of pulse vaccination campaigns between a homogeneously and heterogeneously structured population

Table 7.2 to 7.6 demonstrate the impact of asynchronized pulse vaccination in heterogeneously structured population at different inter-vaccination intervals and coverage levels. In comparison with the homogeneously structured population and at a given inter-vaccination interval and coverage level the heterogeneously structured population required higher vaccination coverage levels than homogeneously structured population. In addition the model also predicted unrealistically higher number of rabies cases at lower vaccination coverage levels and longer inter-vaccination interval within the heterogeneously structured population in comparison with the homogeneously structured population.

Table 7. 2: Comparison of mean number of rabies cases between heterogeneously and homogeneously structured dog populations with the asynchronized campaign and four month inter-vaccination interval

Vaccination coverage (%)	Mean number of cases per month in a homogeneous population	Mean number of cases per month in a heterogeneous population
20	1.3	794
25	0.9	1.6
30	0.8	0.9
35	0.6	0.8
40	0.5	0.6
45	0.4	0.5
50	0.4	0.4
55	0.3	0.4
60	0.3	0.3
65	0.3	0.3
70	0.2	0.2
75	0.2	0.2
80	0.2	0.2
85	0.2	0.2
90	0.2	0.2
95	0.1	0.1

Table 7. 3: Comparison of mean number of rabies cases between heterogeneously and homogeneously structured dog populations with the asynchronized campaign and six month inter-vaccination interval

Vaccination coverage (%)	Mean number of cases per month in a homogeneous population	Mean number of cases per month in a heterogeneous population
20	2.0	1378.0
25	1.4	1073.0
30	1.1	737.0
35	1.0	2.0
40	0.7	1.0
45	0.7	0.7
50	0.6	0.6
55	0.5	0.5
60	0.4	0.4
65	0.4	0.4
70	0.3	0.4
75	0.3	0.4
80	0.3	0.3
85	0.2	0.2
90	0.2	0.2
95	0.1	0.1

Table 7. 4: Comparison of mean number of rabies cases between heterogeneously and homogeneously structured dog populations with the asynchronized campaign and six month inter-vaccination interval.

Vaccination coverage (%)	Mean number of cases per month in a homogeneous population	Mean number of cases per month in a heterogeneous population
20	2.6	2194.0
25	2.0	1440.0
30	1.5	1236.0
35	1.3	1002.0
40	1.2	1.9
45	1.0	1.6
50	0.7	0.9
55	0.7	0.8
60	0.6	0.7
65	0.6	0.6
70	0.5	0.5
75	0.5	0.5
80	0.4	0.4
85	0.3	0.4
90	0.3	0.3
95	0.1	0.2

Table 7. 5: Comparison of mean number of rabies cases between heterogeneously and homogeneously structured dog populations with the asynchronized campaign and 10 month inter-vaccination interval

Vaccination coverage (%)	Mean number of cases per month in a homogeneous population	Mean number of cases per month in a heterogeneous population
20	4.0	3047.0
25	3.0	2296.0
30	2.0	1460.0
35	2.0	1307.0
40	1.3	1130.0
45	1.1	913.0
50	1.0	36.0
55	0.9	1.2
60	0.8	1.0
65	0.7	0.9
70	0.6	0.8
75	0.5	0.6
80	0.5	0.5
85	0.5	0.5
90	0.4	0.4
95	0.4	0.3

Table 7. 6: Comparison of mean number of rabies cases between heterogeneously and homogeneously structured dog populations with the asynchronized campaign and 12 month inter-vaccination interval.

Vaccination coverage (%)	Mean number of cases per month in a homogeneous population	Mean number of cases per month in a heterogeneous population
20	5.3	3598.0
25	3.3	3019.0
30	2.3	1769.0
35	2.2	1495.0
40	1.6	1368.0
45	1.5	1229.0
50	1.4	1066.0
55	1.0	888.0
60	0.9	406.0
65	0.9	1.2
70	0.8	0.8
75	0.7	0.8
80	0.6	0.6
85	0.5	0.6
90	0.5	0.5
95	0.5	0.5

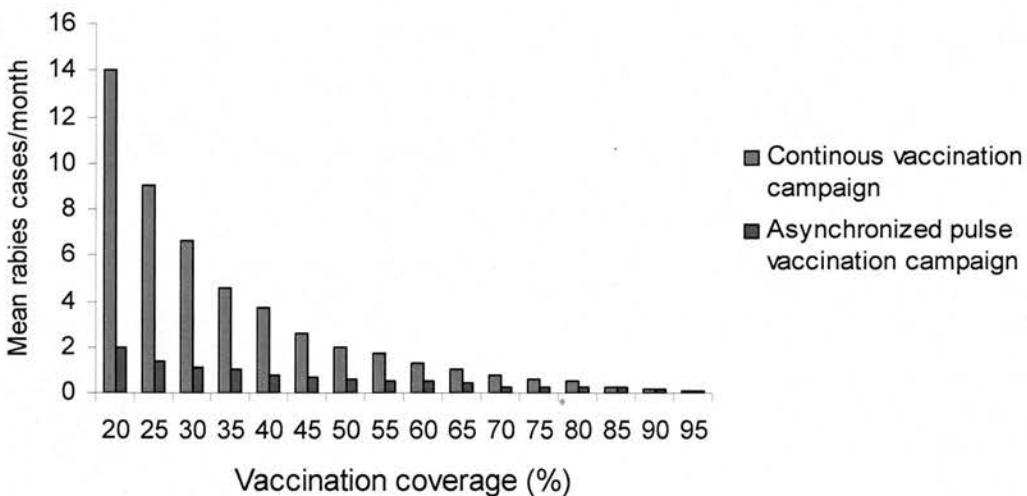
7.2.4. Impact of varying inter-vaccination intervals

The model predicted higher reduction in rabies incidence when the pulse vaccination campaign is repeated after six months or less than when repeated after every 8 to 12 months (Table 7.2 -7.6).

7.2.5. Comparison between pulse and continuous vaccination campaigns

The impact of pulse and continuous vaccination campaign is illustrated in Figure 7.11. The model results demonstrated that continuous vaccination campaigns are likely to be less effective than asynchronized pulse vaccination campaigns. Asynchronized six month inter-vaccination interval pulse vaccination campaigns resulted in lower mean number of rabies cases per month than a continuous vaccination campaigns.

Figure 7. 7: The impact of asynchronized pulse vaccination repeated after every six months in comparison with the continuous vaccination strategy on mean number of rabies cases per month



7.3. Discussion

This study is the first theoretical attempt to explore the design of domestic dog mass vaccination campaigns in rural Tanzania. The results from the model therefore only give an indication of possible future directions that needs to be considered for an effective rabies control programme in rural Tanzania. The model used in this study is likely to require further improvements to adequately address various domestic dog population heterogeneities that are likely to be associated with rabies transmission. However, although the modelling results presented in this chapter are only preliminary findings and largely theoretical, they are likely to give useful insights into real-life dynamics of rabies and its control.

The basic reproductive number R_0 is considered to be linearly dependent on population size. In larger populations higher values of R_0 would results in increased number of monthly rabies incidence due to more secondary cases generated from one infected dog. Therefore to control rabies in larger domestic dog populations is likely to require higher vaccination coverage levels than smaller populations.

The rabies incidence data generated in this model depended largely on the relationship between R_0 and the domestic dog population size. Despite constraining the value of R_0 to not more than three, the number of rabies cases generated by the model in a heterogeneously structured population was unrealistically higher than would be expected. This defied the assumed linear relationship between R_0 and dog population size. This finding highlights the possibility of a more complex relationship between R_0 and population size than originally thought and underscores our potentially limited knowledge and understanding about this relationship. Further

studies that would investigate the relationship between R_0 and population size need to be considered.

Theoretical studies and empirical observations recommend instantaneous vaccination coverage of 70% in order to prevent major rabies outbreak from occurring (World Health Organization, 1992; Coleman & Dye, 1996). The model results in this study demonstrate that a critical inter-vaccination interval and threshold vaccination coverage are likely to be critical factors for rabies control by mass vaccination of domestic dogs.

The effectiveness of high vaccination coverage rates for rabies control has been demonstrated in several empirical studies where vaccination coverage levels ranging from 65 to 88% resulted in substantial decline in rabies incidence (Cleaveland *et al.*, 2003; Belotto, 1988; Ben-Osman and Haddad, 1988; Chomel *et al.*, 1988). However achieving such high coverage levels is likely to pose a substantial logistic, financial and human resource challenge. Shorter inter -vaccination campaigns (such as biannual campaigns) are likely to offer an effective alternative to the conventional annual campaigns. The advantage of shorter inter-vaccination campaigns resides in their effectiveness at even lower coverage levels which were shown to be as low as 50% in this study. However the cost-effectiveness of such biannual versus annual vaccination campaigns still needs to be investigated.

Theoretical studies have identified heterogeneities in host populations as key factors for the design of optimal disease control programmes. Some studies have suggested targeting of disease control programmes to specific high risk segments of the host

population. For rabies control some of the high risk segments are likely to include high density dog populations as contacts rates and hence the basic reproduction number (R_0) is likely to be higher within these populations. One likely targeted measure would be to direct more vaccination effort and higher vaccination coverage to villages with higher dog populations than those with low population size. The model findings suggest that it will be more difficult to control rabies in an area with highly variable dog population size than where the variability is low. High variability in dog population size is likely to result in parallel variability in R_0 (which is dependent on the abundance of susceptible and infectious host population). Domestic dog populations with less variable and lower population sizes are therefore likely to require less vaccination effort to reduce the value of the basic reproductive number (R_0) to less than one. However, although heterogeneities in dog population size are important, they are only likely to have a significant impact at low vaccination coverage levels and longer inter-vaccination intervals. Results from the model indicate that control of rabies is likely to be more difficult with patchy vaccination coverage than homogenous coverage highlighting the need for vaccination strategies that will ensure that not only is the required coverage achieved but it is achieved and maintained uniformly across an epidemiological cluster (such as a district).

Inter-vaccination interval demonstrated a significant impact on incidence of rabies in both homogenous and heterogeneous dog populations with the lowest incidence recorded at the shortest intervals. Due to the high turn-over rate of dog population in

rural Tanzania, Cleaveland (1996) has recommended six to eight months as the optimal inter-vaccination interval instead of the conventional annual vaccination campaigns. Results from this model demonstrate that shorter inter-vaccination interval are likely to have the largest impact in terms of rabies incidence reduction..

The traditional central point vaccination system operates on the basis of a one-year interval pulse vaccination strategy, using vaccination teams which move from one place to the other, asking owners to bring dogs to a centralized point for rabies vaccination. Such campaigns may be synchronized over a wider zone and the feasibility of this approach for dog rabies has been demonstrated in parts of central and South America with the designation of a national ‘rabies day’, during which community resources are mobilised locally to allow synchronization of dog vaccination campaigns nationwide (Belotto, 1988). Overall the model predicted slightly lower number of rabies cases with synchronized campaigns than asynchronized campaigns. Synchronized campaigns are therefore likely to be more effective than asynchronized campaigns in reducing dog rabies incidence. In addition synchronized vaccination campaigns may also be preferred due to its likely better economic and organizational effectiveness.

The current model explored the optimal design of domestic dog vaccination in only one district out of the 134 districts in the country. Clearly the findings of the model are only preliminary and may not necessarily be applicable for the rest of the country. In future the model could be improved and adapted to address key strategic factors relevant for the design of rabies control for the entire country.

Chapter VIII: General Discussion

Rabies remains uncontrolled in Tanzania with the incidence of the disease generally increasing. Little efforts have been devoted by the government as a whole to control the disease. According to the Ministry of Livestock Development (2006) the major constraints for rabies control in the country have been lack of adequate resources and absence of collaborative efforts among different sectors that are likely to benefit from rabies control. This is likely to be aggravated by the absence of adequate information to inform policy makers and practitioners on appropriate rabies control strategies and economic data on the costs and benefits of rabies control. Data generated from this study provides comprehensive information that will provide a valuable guidance to policy makers and practitioners with regard to rabies control in rural Tanzania and elsewhere in Africa.

The major finding of this study is its ability to demonstrate empirically that simple central point domestic dog mass vaccination provides an effective and viable rabies control strategy for most of the agro-pastoral rural community in Tanzania. In addition controlling rabies in domestic dogs led to marked reduction in the incidence of human bites from suspected rabid dogs. The study also demonstrates that for effective rabies control in pastoral communities a different strategy will be required, underscoring the likely need of socio-culturally adapted ways of implementing domestic dog vaccination programmes in some rural communities of the country.

This study was largely based on questionnaire survey as a tool to measure and evaluate diverse qualitative and quantitative variables relevant for optimising the design and implementation of domestic dog mass vaccination programmes in rural

Tanzania. However it should be borne in mind that data collection through questionnaire survey may not be completely objective or consistent. Interviewers and respondents are all human beings and are likely to have psychological, emotional, and social bias. Too often, questionnaire survey may fail to take these factors into account when planning, undertaking, and analysing data. This study acknowledges these limitations.

A major limitation of the present questionnaire survey is related to its ability to measure correctly and consistently the age of dogs. Questionnaire validation revealed inconsistencies in age of dogs given by respondents. The survey however used all possible means to make sure that ages given by owners reflected the precise age as much as possible through the use of several validation approaches as explained in Chapter II. Questionnaire validation demonstrated no significant effect of the on age class distribution of the dog population. The age distribution pattern across the three years in which the household questionnaire survey was administered remained consistent.

The questionnaire survey in this study relied largely on a single household respondent who was normally the head of household. In the case of factual quantitative questions it seems reasonable to rely on a single responsible adult respondent. However when sampling opinions and attitudes it is less clear that a single “convenient” household respondent can adequately represent the views of “the household”, each member of which may actually have different views and preferences. The use of a single “convenient” respondent therefore is likely to result

in substantial biases because the views of other household members are likely to be under-represented. This was however mitigated by sampling a large number of households in each village which increased the probability of interviewing individuals from with diverse views about variable that were investigated in the study.

Despite its limitations the study was generally able to sufficiently address the key questions it intended to answer. In chapter 2 the study demonstrates the robustness of central point vaccine delivery approach across different socio-economic settings in agro-pastoral rural Tanzania. Tanzania is largely a rural country with 68% of the population living in rural areas. This implies that the central point vaccination approach is likely to be effectively applicable to a large part of the country. Despite the country being culturally diverse with 120 different ethnic groups, the social and cultural attitudes towards dogs are less likely to vary widely particularly due to the fact that 95% of all ethnic groups in the country have a common ancestry rooted in the Bantu origin and therefore share numerous common social and cultural values. Religious factors however need to be considered carefully as this study did not address itself sufficiently into this aspect. It is known that central point dog vaccination campaigns have been comparatively unsuccessful in predominantly Muslim communities. In Tanzania Muslims form 33% of the population which is a substantial proportion. However due to religious restrictions, most of the Muslim community is unlikely to own a substantial number of dogs. In addition, the Muslim communities inhabit urban areas of the country and/ or historically clearly

demarcated and isolated areas, which make targeting them with effective tailored strategies comparatively easier.

The question of long-term sustainability of rabies vaccination programme is likely to be a critical consideration in Tanzania and in much of the developing world countries. Sustainability in the context of rabies vaccination programmes should not only mean the ability to continue carrying-out rabies vaccination programmes but, more importantly, should be the ability to sustain high coverage levels for a considerable length of time. Due to its heavy reliance on external input and funding the sustainability of rabies control programmes such as the one in the present study remains highly questionable. Long-term sustainability of rabies control is likely to depend on the extent to which rabies control is integrated into the government public health policies. For this to occur the disease needs to be perceived as a priority by both the government and local communities. A multi-sectoral approach for rabies control involving key local stakeholders for the disease is likely to be a viable option for a sustainable long-term rabies control.

In chapter three the study demonstrated that rabies is a substantial economic concern to households in rural Tanzania, disproportionately affecting households with low socio- economic status. The study also demonstrated that dog bite victims with low socio economic status are at higher risk of dying from rabies. Communities in rural Tanzania indicated that they fear rabies more than malaria despite the lower incidence of rabies highlighting the magnitude of psychological and economic

burden which rabies imposes upon the community. PEP is usually available only at district hospital in urban areas which are often located far away from most of the rural areas where most bites from suspected rabid dogs occur. This imposes unnecessary additional burden to rural communities which are already under-privileged and marginalized. The ministry of health has in place an effective infrastructure for vaccine delivery up to village level under the EPI. Rabies PEP could be incorporated into the EPI vaccine programme to help make its availability easier to dog bite victims from rural communities who suffer disproportionately higher from rabies compared to urban communities. The Tanzanian health authorities use a truncated PEP schedule of three injections on days 0, 7 and 28. The basis for this truncated schedule is not clearly known. The only clear point is that the Tanzania PEP schedule falls far short of the WHO recommendations for PEP and is likely to be associated with human deaths in treated bite victims. Although this study did not evaluate the efficacy of the Tanzania truncated schedule it would be in the best interest of public health in the country to re-consider the schedule so that it is in accordance with the WHO recommendations.

In Chapter four the study demonstrates that controlling canine rabies would be an economically effective rabies control strategy that could result in a substantial net public health benefits in terms of savings on PEP expenditures. The study also demonstrates that central point vaccine delivery approach offers an effective vaccine delivery strategy for rural agro-pastoral communities in Tanzania. However the central point vaccine delivery approach was not a viable strategy in remote pastoral Maasai communities with the coverage attained in this study well below the

recommended target for rabies control and the *per capita* dog vaccination cost higher in comparison with the agro-pastoral communities. This finding raises important questions on the design and implementation of dog vaccination campaigns in remote pastoral communities particularly on the blanket applicability of central point dog mass vaccination campaign against rabies. The finding highlights the need for identification and utilization of alternative rabies control strategies for the pastoral community settings.

In chapter five the study demonstrated that vaccination of domestic against rabies that also provides protection against some important canine infections such as canine distemper, parvovirus and hepatitis results into increased survival and growth of domestic dog population. Despite the increase in dog population survival and growth rate there was no evidence of increase in the number of feral dog highlighting presence of substantial demand for additional new dogs. In the absence of high demand for new dogs population control measures would have been an important factor to consider under these circumstances. The dog owners and the community as a whole was fully aware of the possible problems likely to be associated with dog population explosion and described traditional approaches for controlling dog population. However for animal welfare reasons humane ways of dog population control such as sterilization and use of contraceptives would need to be considered in case the need for population control arises.

In chapter six the study demonstrates a substantial decline in incidence of human and animal rabies as a result of dog vaccination highlighting the effectiveness of domestic dog vaccination as a tool for rabies control in rural Tanzania. However, despite a decline in reporting of animal rabies cases and human bite injuries from suspected rabid dogs, use of PEP at district hospitals did not decline. The correlation between decline in incidence of animal rabies and demand for PEP has been not adequately investigated in rural Africa. In the present study a possibility of inappropriate use of PEP at district hospitals can not be ruled out.

The rabies model results demonstrate several issues relevant for designing of rabies vaccination programmes. Inter-vaccination interval is likely to be a critical factor if rabies is to be controlled. The conventional annual vaccination campaigns are likely to be insufficient for controlling the disease. This study recommends a six months inter-vaccination interval as the optimal interval for rabies control in Tanzania. In addition, the possibility of synchronizing rabies vaccination campaigns over a wide area needs to be considered. Synchronizing vaccination campaigns is likely to result into substantial logistic and economic benefits.

Human deaths from rabies are almost entirely preventable through control of rabies in the animal reservoir (principally the domestic dog in Africa). Yet despite the availability of proven effective control measures (Bogel and Meslin, 1991; WHO, 2005; Belotto et al., 2005), the disease remains neglected throughout most of the African continent, partly because of its perceived low priority. The findings of this study have clearly demonstrated the feasibility and effectiveness of large-scale dog

vaccination campaigns for control and elimination of dog rabies at a national level. The domestic dog vaccination campaigns resulted in up to a > 87% reduction in dog rabies cases and human animal-bite injuries occurring within 2-3 years on implementing dog vaccination campaigns. In addition, the *per capita* cost of dog vaccination for a wide range of rural agro-pastoral and pastoral communities. The vaccination coverage in all situations reached the target threshold level recommended for rabies control (~70%) and has been achieved through relatively simple programmes of parenteral dog vaccination.

WHO reports that rabies is perceived by many high-ranking/decision-making public health and animal health officers as a "rare disease of humans" resulting from the bite of a non-economical animal (the dog). A further problem is that rabies control (primarily through dog vaccination) has traditionally been the responsibility of the veterinary services, yet the economic and health burden of the disease falls most heavily on the public health sector. For all of these reasons rabies control has been largely neglected. Yet the disease has features which would make it an excellent target for disease control initiatives. Control of rabies is feasible and likely to be cost-effective; the tools for rabies control are currently available; and control measures are likely to have immediate and profound impacts that make it an attractive disease for funding.

Rabies also satisfies the criteria set out by the World Health Organization for identifying diseases as priorities for control, that is, rabies is:

- a vaccine preventable disease (in both humans and animals).
- a disease of poverty affecting very vulnerable often remote/isolated rural populations.
- a disease of young people (mostly affecting the age class 5-15 years).

The key elements are now in place to develop an effective, integrated national strategy for rabies control in Tanzania with collaborative efforts by the Ministries of Livestock Development, Health and Wildlife a benchmark for the successful control of rabies in Africa.

There is no doubt that control of dog rabies, and elimination of human deaths from canine rabies through implementation of mass dog vaccination and optimised delivery of human PEP, is a realistic prospect for Tanzania that could result in major public health and economic benefits and act as a flagship programme for rabies control in Africa.

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Appendix I

Vaccination attitudes questionnaire

Date: _____ Name of Head of household _____

Occupation: Employed Farmer Unemployed Business Others

If employed, what is occupation.....

Religion:.....

Number of people in the household

Education :Primary Secondary College University None

Name of village.....Name of Balози.....

GPS location

Name of District.....

Socio-economic status assessment

Housing data

Wall Material (<i>Cement Block/ Mud/ Earth Brick/ Baked Earth Brick</i>)	Roof Material (<i>Grass /Iron sheets</i>)	Floor Material (<i>Earth/ Cement</i>)	General Comment

Agricultural implements and bicycle data:

Equipment	Number of each type of implement
Ox plough	
Ox harrow	
Ox ridger	
Ox weeder	
Ox cart	
Bicycle	
Radio	

Livestock data

	Number of cattle	Number of sheep	Number of goats	Poultry	Others
Adults					
Young					

Have you heard of the disease rabies?

Yes No

What do you know about rabies?

.....

Do you know how rabies can be prevented?
 in humans.....

.....
 ...

in animals

Is the animal rabies vaccine available in your area?

Intermittently All the Never

Is the human rabies vaccine available in your area?

Intermittently All the time Never

Do you think dog vaccination against rabies is a good idea?

Yes No

Give reasons.....

.....

Would you bring your dog to a central vaccination point for rabies vaccination?

i. If vaccination is free Yes No

ii. If you have to pay for vaccination Yes No

Give reasons for the answer in question above.....
.....
.....

Appendix II

Post vaccination household questionnaire survey

Date.....Village.....
 Subvillage.....
 District..... GPS.....
 Distance from nearest neighbour.....
 Interviewer.....
 Name of head of household.....
 Name of ten cell unit leader.....
 Tribe.....
 Number of people in household.....
 Number on last years questionnaire form.....

Information on dog, vaccination and bleeding:

Number of dogs in household:.....dogs three months old or less..... number of dogs over three months old.....

Name of dog	Sex	Age (years/months)	Dog vaccinated? Yes/No	Year dog vaccinated	Source of dog (born from home/same village/neighbouring village)

If there is any dog that was not vaccinated please give reasons:

.....
.....
Is there any dog that suffered from any post- vaccination problems? Yes/No. If yes describe:.....
.....
.....

How many dogs do you think are enough to meet your household needs
Why do you think the number of dogs you have mentioned is enough?.....
.....
.....
.....
.....
.....
.....
.....

If you have got more dogs than your need what would you do to the extra dogs?
.....
.....
.....
.....

If your dog has whelped more puppies than your needs and you can not give away all the puppies whelped what will you do to the remaining puppies?
.....
.....
.....
.....
.....

Would you consider starving/neglecting/ killing puppies as a measure of dog population control?..... Give reasons for your answer.....
.....
.....
.....
.....

Do you think there have been any changes in the dog population over the last 2 years?
Yes/No

Which changes do you think have occurred?
.....

Do you think changes in dog population are causing any problem? Yes/No

Explain why?.....

.....
.....

If you think dog population changes are causing problem what measures do you suggest should be taken to control the changes?

.....
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.....

Is there any dog born after the most recent vaccination campaign? Yes/No. If yes how many dogs?

Have you acquired any dog after the most recent vaccination campaign? Yes/No If yes how many dogs? How many of the acquired dogs were vaccinated in the most recent campaign?.....

Have you given away any dog after the last most recent vaccination campaign? If yes how many dogs?..... How many of these were vaccinated in the most recent campaign?...

Is there any dog that has died since the most recent recent vaccination campaign? If yes how many dogs?..... How many out of those that died were vaccinated in the most recent campaign?.....

Kuna mbwa yeyote aliyekufa baada ya chanjo iliyofanyika hivi karibuni? Ndiyo/Hapana. Kama ndiyo ni mbwa wangapi?.....
Ni wangapi kati ya mbwa waliokufa walikuwa wamechanjwa kwenye chanjo iliyofanyika hivi karibuni?.....

Is there any dog that died in the last 12 months in your household? If yes give details below:

Name of dog	Sex	Death age	Month dog died	Cause of death

Did you acquire any dog to compensate for those that died? Yes/No. If yes give details:

Name of dog	Sex	Age	Source	After how long was the replacement done

Livestock information:

How many livestock do you have?

How many livestock do you have?

< 10 10-50 50-100 100-200 200-300 300-400 400-500 > 500

Cattle		Goats		Sheep		Donkeys	
Young	Adult	Young	Adult	Young	Adult	Young	Adult

Were any of your livestock/dogs bitten/attacked by an animal in the past 12 months?

Yes/ No. If yes fill in the table below:

Date of attack	Type of attacking Animal	Type of animal Attacked	If dog, Name	No. of live stock bitten	Outcome dead/recov/injur	If died, how long after attack	Attacker suspect rabies Y/N

Attacker: if suspect rabies, why? Please, indicate time, circumstances, clinical signs shown and any other relevant information.....

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Bitten/attacked animal: if suspect, why? Please, indicate time, circumstances, clinical signs shown and any other relevant information.....

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Additional dog information:

Have you ever seen any ownerless dog in this village? Yes/No. If yes how many dogs and how often in a week do you see these ownerless dogs?.....

.....

Have you ever seen any free roaming dog in this village? Yes/No. If yes how many have and how often in a week do you see these free roaming dogs?.....

.....
.....

Do you restrict your dog from going out of the household? Yes/No. If yes what time of a day do you restrict your dog?

.....

 What means do you use to restrict your dog? Rope/fence.
 Describe if other means used.....

Do you have any dog with a wound or scar? Yes/No. If yes please complete the following information:

Name of dogs	Cause of wound/Scar	Date the injury occurred

Why do you keep dog(s)

FEMALE DOGS FERTILITY INFORMATION:

Dog 1:

Name of dog.....Age..... How many times has the dog whelped?.....Has the dog whelped in the last 12 months? Y/N

If yes when..... How many puppies?..... How many died?..... Cause of death.....

How many killed?..... Why killed?.....

How many given away?..... Why given away?.....Where given away (same or other village).....How many remaining?.....

Dog 2:

Name of dog.....Age..... How many times has the dog whelped?.....Has the dog whelped in the last 12 months? Y/N

If yes when..... How many puppies?..... How many died?..... Cause of death.....

How many killed?..... Why killed?.....

How many given away?..... Why given away?.....Where given away (same or other village).....How many remaining?.....

Dog 3:

Name of dog.....Age..... How many times has the dog whelped?.....Has the dog whelped in the last 12 months? Y/N

If yes when..... How many puppies?..... How many died?..... Cause of death.....

How many killed?..... Why killed?.....

How many given away?..... Why given away?.....Where given away (same or other village).....How many remaining?.....

Dog 4:

Name of dog.....Age..... How many times has the dog whelped?.....Has the dog whelped in the last 12 months? Y/N

If yes when..... How many puppies?..... How many died?..... Cause of death.....

How many killed?..... Why killed?.....

How many given away?..... Why given away?.....Where given away (same or other village).....How many remaining?.....

Dog 5:

Name of dog.....Age..... How many times has the dog whelped?.....Has the dog whelped in the last 12 months? Y/N

If yes when..... How many puppies?..... How many died?..... Cause of death.....

How many killed?..... Why killed?.....

How many given away?..... Why given away?.....Where given away (same or other village).....How many remaining?.....

Rabies information:

Have you ever heard of any animal or human rabies case in this village or neighbouring village for the past one year? Yes/No. If yes please give the following information

Case 1:

Animal species..... Date.....

Name (if human case)..... Sex.....

Age.....

If known dog, name of dog..... Sex..... Age.....

Name of dog owner.....

Information about rabies case:

Please take detailed information about the rabies case including history, symptoms shown, date symptoms appeared, date of bite and fate of the victim. If it is an animal indicate how many other animals or human were bitten by the suspected rabid animal.

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Case 2:

Animal species..... Date.....

Name (if human case)..... Sex.....

Age.....

If known dog, name of dog..... Sex..... Age.....

Name of dog owner.....

Information about rabies case:

Please take detailed information about the rabies case including history, symptoms shown, date symptoms appeared, date of bite and fate of the victim. If it is an animal indicate how many other animals or human were bitten by the suspected rabid animal.

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Case 3:

Animal species..... Date.....

Name (if human case)..... Sex.....

Age.....

If known dog, name of dog..... Sex..... Age.....

Name of dog owner.....

Information about rabies case:

Please take detailed information about the rabies case including history, symptoms shown, date symptoms appeared, date of bite and fate of the victim. If it is an animal indicate how many other animals or human were bitten by the suspected rabid animal.

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Is there any household member of has ever been bitten by a suspected rabid dog? Yes/ No. If yes please take the following information:

Household member 1

Name of person bitten.....

Species of animal that inflicted the bite.....

If the animal is dog Name of dog if known.....

Date bitten.....

Symptoms by bite victim.....

.....
.....

Treatment given.....

.....
.....

Fate of the bite victim (Recovered or died).....

.....

Household member 2

Name of person bitten.....

Species of animal that inflicted the bite.....

If the animal is dog Name of dog if known.....

Date bitten.....

.....
.....

Symptoms by bite victim.....
.....
.....
Treatment given.....
.....
.....
Fate of the bite victim (Recovered or died).....
.....

Household member 3

Name of person bitten.....
Species of animal that inflicted the bite.....
If the animal is dog name of dog if known.....
Date bitten.....
Symptoms shown by bite victim.....
.....
.....
Treatment given.....
.....
.....
Fate of the bite victim (Recovered or died).....
.....
.....
How many people are there in the household?

Appendix III

Dog bite trace back questionnaire

Name of patient:Age..... Sex.....

If patient is not the respondent person providing the information:.....
.....

Marital status: Married Single Widowed Divorced

Education: Primary Secondary College University None

Occupation: Employed Farmer Unemployed Business
Others.....

Tribe..... Religion:.....

Name of village..... Name of ten cell unit leader.....
.....

Number of people in household.....

GPS location..... Rural/ urban

District.....

Bite records

What animal species bit you?

If dog: own dog known dog unknown dog

If known dogs what actions taken against the dog owner.....
.....
.....

Site of bite:.....

Severity of wound.....
.....
...

Circumstances of bite.....
.....

Number of other people bitten by same dog.....

Rabies assessment: Rabid / not rabid/ don't know. Describe in details.....
.....

If the bite victim has died, what was the cause of death? (Describe signs if possible)
.....
.....

When did the patient die?

Treatment records

- Where did you get treatment after the dog bite
- First aid (eg.washing wound)
- Private dispensary
- Bought medicines
- District hospital
- Local treatment
- Outside the district (specify eg nearby district Kenya)

What type of treatment did you get at the health facility? Explain.....
.....
.....

For post exposure treatment (PET) fill in the table:

Treatment	PET 1	PET 2	PET 3	PET 4	PET 5
Date					

Who paid for your treatment?
Self owner of dog Relative Others.....

How was the money raised?.....
.....
.....
.....

Do you think the treatment given is helpful?

Describe.....

.....
....

If no full course of PET administered give reason why?.....

.....
.....
.....

Loss of work time record

How have the injuries inflicted affected your daily life? Explain

.....
.....
.....

How much total time did you spend to get to the health care facility for treatment?

	Local healer	Dispensary	Hospital
Hours			
Days			

How much money did you spend for treatment?

	Local healer	Dispensary	Hospital
Registration			
Laboratory			
Drugs			
Transport			
Others			

Were you accompanied by anybody else to the health care facility? Give relationship, age and occupation of the person who accompanied you and cost incurred for the person(s).

Relationship..... Age..... Sex..... Occupation.....

	Local healer	Dispensary	Hospital
Costs for accompanying person(s)			

Did you lose friends as a result of having been bitten by a suspected rabid animal?

YES NO

Explain.....

Are the medical personnel handling you fairly like in other disease conditions?

YES NO

Explain.....

.How do you compare a bite by a rabies suspect animal with malaria?

Explain.....

Socio-economic status assessment
 Housing data

Wall Material (Cement Block/ Mud/ Earth Brick/ Baked Earth Brick)	Roof Material (Grass /Iron sheets)	Floor Material (Earth/ Cement)	General Comment

2. Agricultural implements and bicycle data:

Equipment	Number of each type of implement	Year acquired	Purchase price (shs)	Condition (Working/Not Working)
Ox plough				
Ox harrow				
Ox ridger				
Ox weeder				
Ox cart				
Bicycle				
Radio				

Livestock data

	Number of cattle	Number of sheep	Number of goats	Poultry	Others
Adults					
Young					

How much money do you spend per month/day for household expenditures?

.....
.....

Appendix IV

Cases of animal bites: questionnaire to administer to patients

Please administer Part I of this questionnaire at the beginning of treatment to patients presenting with animal bites, and Part II after completing the treatment.

Name of Interviewer _____

Title _____

Address of Treatment _____

Centre/Hospital _____

Part I

Name of patient _____ Age of patient _____

Sex Male Female

Date of presentation _____ Date of contact with animal _____

Geographic origin of patient:

Village/town _____ Sub Village _____

District _____

What animal bit the patient?

If a dog bite, was the dog known? Yes No Dog name/description _____

What were the circumstances of the attack?

On what part of the body was the patient bitten? (tick all which apply)

Head/Neck Arms Upper trunk Lower trunk Legs

Notes _____

Multiple bites? Yes No

For any of the above bites, was the skin broken? Yes No

Additional description of injury: _____

Was any other person bitten by the same animal? Yes No If yes, how many others? _____

Was any other animal bitten by the same animal? Yes No If yes, what type of animal? _____

Was the animal suspected to be rabid? Yes No If yes, why?

Was the wound washed prior to presentation? Yes No If yes, was soap used?
Yes No

Other than washing, did the patient receive any treatment elsewhere prior to presentation?
Yes No
If yes, please give details _____

At presentation at your hospital/clinic, was treatment given? Yes No

If yes:

Washing of wound? Yes No

Tetanus toxoid? Yes No

Antibiotics? Yes No

If yes, which antibiotic? _____

Part II

Was rabies post exposure treatment (PET) recommended? Yes No

If yes, what was given?

Rabies immune-globulin? Yes No

Rabies vaccine? Yes No

If yes, tick doses given

(1st) _____

(2nd) _____

(3rd) _____

(4th) _____

(5th) _____

Outcome of treatment of patient _____

Was the animal reported to/or investigated by a veterinary worker? Yes No

What happened to the biting animal? _____

Appendix V: Domestic dog vaccination cost-benefit analysis

Year	Phase	Area	Number of dogs vaccinated	Cost of vaccinating dogs US \$	Number of people in target area	Number of suspect dog bites prevented	Cost of post-exposure treatments saved US\$	Human lives saved	DALYs saved	Cost Benefit Ratio	Cost per DALY saved
2003	Stabilization	6,992.00	48,944	83,205	466,989	1,261	70,609	126	3,909	1.27	21.28
2004	Stabilization	6,992.00	58,243	99,014	480,999	1,299	72,727	130	4,026	1.36	24.59
2005	Elimination	6,992.00	66,980	113,866	495,429	1,338	74,909	134	4,147	1.52	27.45
2006	Elimination	6,992.00	73,678	125,252	510,291	1,378	77,156	138	4,271	1.62	29.32
2007	Elimination	6,992.00	77,362	131,515	525,600	1,419	79,471	142	4,399	1.65	29.89
2008	Elimination	6,992.00	81,230	138,091	541,368	1,462	81,855	146	4,531	1.68	30.47
2009	maintenance	675.00	4,725	8,033	557,609	1,506	84,311	151	4,667	0.09	1.72
2010	maintenance	675.00	4,725	8,033	574,338	1,551	86,840	155	4,807	0.09	1.67
2011	maintenance	675.00	4,725	8,033	591,568	1,597	89,445	160	4,951	0.08	1.62
2012	maintenance	675.00	4,725	8,033	609,315	1,645	92,128	165	5,100	0.08	1.57
2013	maintenance	675.00	4,725	8,033	627,594	1,695	94,892	169	5,253	0.08	1.52
2014	maintenance	675.00	4,725	8,033	646,422	1,745	97,739	175	5,411	0.08	1.48
2015	maintenance	675.00	4,725	8,033	665,815	1,798	100,671	180	5,573	0.07	1.44
2016	maintenance	675.00	4,725	8,033	685,789	1,852	103,691	185	5,740	0.07	1.39
2017	maintenance	675.00	4,725	8,033	706,363	1,907	106,802	191	5,912	0.07	1.35
Total			-	763,235		23,451	1,313,246	2,345	72,698	0.6	10.5