DEMOGRAPHICS OF AN OWNED DOG POPULATION IN BUSHBUCKRIDGE, MPUMALANGA PROVINCE, SOUTH AFRICA

By

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Dedication

For He who is mighty has done great things for me, and holy is His name and His mercy is on those who fear Him (Luke 1:49)

Hence magnify the lord with me, and let us praise His name together (Psalm 34:3)

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Demographics of an owned dog population in Bushbuckridge, Mpumalanga Province, South Africa

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Abstract

Rabies can be controlled and human deaths reduced through the mass vaccination of domestic dogs, as recorded in some parts of the world. However, in sub-Saharan Africa rabies infection is on the increase, largely due to the population dynamics that favour disease transmission. The demographics of the dog population in this study area are unknown. This study describes the demography of owned dogs in a rural sub-Saharan African setting. The study took place in Hluvukani, in the Mnisi area of Bushbuckridge Local Municipality, Mpumalanga Province in South Africa. A full census of the dog population in the study area was conducted at two time points. The first census took place from July through October 2011, followed by a second census from May through October 2013. The first census was accompanied by a house-to-house rabies vaccination campaign.

The demographic surveillance area covered 10.4 km^2 and comprised around 2,000 households, with a mean household size of 4.9, a density of 913 people/km^2 and a human:dog ratio of 14:1. Results in the first and second census respectively indicated a dog density of 77 dogs/km^2 and 84 dogs/km^2, and a sex ratio of 1.32 and 1.47 males per female. Household indicators in the first and second censuses respectively showed the number of households as 1,907 and 1,939; and the number of dogs as 799 and 870. The mean number of dogs per household (standard deviation) was 0.41 (1.08) and 0.44 (1.16) and the number of dog-owning households was 393 (20.6%) and 416 (21.5%). The mean number of dogs per dog owning household (standard deviation) was 2.03 (1.56) and 2.09 (1.71). Vaccination coverage against rabies achieved by the campaign during the first census was 68.2% (545/799). Vaccination coverage at the time of the second census was 59% (513/870).

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Chapter 1:
Introduction

Rabies virus (RABV), the prototype member of the genus Lyssavirus, family Rhabdoviridae, is a multi-host pathogen capable of infecting a wide range of species (Lembo *et al*., 2007). Rabies is considered to be one of the most significant viral zoonoses (Knobel *et al*., 2005) which has over the years affected tens of thousands of people worldwide. This dreaded disease has the highest human case fatality proportion of any infectious disease (Hampson *et al*., 2009). Knobel *et al*. (2005) reported that 55,000 people die per year. Almost half of these deaths occur in Africa while the majority occur in Asia.

The burden of disease is particularly high in the developing countries of Africa and Asia, where rabies control in dogs is inadequate (Knobel *et al*., 2005). Rabies also incurs a significant cost through post-exposure prophylaxis of humans and through the cost of vaccinations of animals against rabies (Cleaveland, 1998). Rabies is a disease of increasing public health and veterinary importance in Africa (Knobel *et al*., 2005), including South Africa (Gummow, Roefs & de Klerk, 2010). In the sub-Saharan countries of Africa domestic dogs are the main reservoir host of rabies, and are responsible for the majority of human rabies cases (Cleaveland, 1998; Hampson *et al*., 2009; Knobel *et al*., 2008).

Dogs have a high reproductive potential and are capable of rapid population growth (Wandeler *et al*., 1988). Populations of free-roaming dogs in underserved communities are characterized by high birth and death rates and hence high population turnover rates. Rapid population growth, driven by high birth rates, generates a rapidly increasing supply of susceptible animals to maintain cycles of infection. Thus, populations which previously could sustain only sporadic, short lived epidemics may now be large enough to maintain independent cycles of infection and act as reservoirs of rabies (Cleaveland, 1998).

Mass vaccination of dogs is the most effective means to control rabies in these settings. In Western Europe, North America, and Latin America, where populations of dogs are well managed, control of rabies using mass vaccination has proved very successful (Acosta-Jamett *et al*., 2010; Hampson *et al*., 2009). The same cannot be reported in sub-Saharan Africa as mass vaccination has not been as successful in the control rabies. This is evident in the fact that the recommended vaccination coverage of 70% (WHO 1996) in many rural settings has not been achieved. Examples of such setting include rural Tanzania where vaccination coverage of

19.2% was recorded by Kaare *et al*. (2009) and 34.6% recorded in Madagascar (Ratsitorahina *et al*., 2009).

To control rabies, efforts must be made to ensure high vaccination coverage through annual mass vaccination (WHO, 1996). It therefore follows that a good understanding of factors that influence the accessibility of dogs is imperative (Knobel *et al*., 2008). In sub-Saharan Africa most dogs are owned therefore several studies have been conducted through household surveys or censuses in order to determine dog population sizes and demographic parameters (Gsell *et al*., 2012; Knobel *et al*., 2008). The aim of this dissertation was to determine the demographics of an owned dog population in a rabies-affected area in South Africa at two points in time, by conducting a complete census of the population on two occasions.

Chapter 2:
Literature review

Rabies

Rabies is thought to be one of the oldest reported infectious diseases of humans, greatly feared due to its social and emotional impact. It is an acute infection of the central nervous system (CNS), characterized mainly by CNS signs and disorders, and is usually followed by paralysis and death (Koprowski *et al*., 1995). The word rabies comes from the Sanskrit *rabhas,* which means, 'to do violence' while the Greek word for rabies is *lyssa*, derived from the root *lud*, or 'violent'. Rabies is caused by several species of negative-stranded RNA viruses belonging to the genus *Lyssavirus*, family *Rhabdoviridae* of the order Mononegavirales. According to the International Committee on Taxonomy of Viruses (ICTV), the genus *Lyssavirus* is delineated into different virus species based on demarcation criteria such as genetic distance and antigenic patterns in reactions with panels of anti-nucleocapsid monoclonal antibodies (Kuzmin *et al*., 2011). This demarcation is further supported by geographic distribution and host range, as reflected in Table 1.

Lyssavirus species segregate into two phylogroups: phylogroup 1 includes rabies virus (RABV), Duvenhage virus (DUVV), European bat lyssaviruses type 1 and 2 (EBLV 1 and 2), and Australian bat lyssavirus (ABLV), as well as Aravan virus (ARAV), Khujand virus (KHUV), and Irkut virus (IRKV), while phylogroup 2 includes Lagos bat virus (LBV), Mokola virus (MOKV), and Shimoni bat virus (SHIBV). West Caucasian bat virus (WCBV) from Russia is more divergent and does not cross-react serologically with either of the two phylogroups (Kuzmin *et al*., 2011). Two related viruses, Bokeloh bat lyssavirus (BBLV) and Ikoma lyssavirus (IKOV), may be members of the genus but have not as yet been approved as species. Ikoma virus, the most divergent of the lyssaviruses, was detected in Tanzania from a civet in the Serengeti National park (Marston *et al*., 2012), but has not yet been classified.

Rabies virus (RABV), the prototype lyssavirus, is the causative agent of classical rabies and is responsible for the majority of human lyssavirus cases (Hanlon & Childs, 2013). RABV is found worldwide, maintained by terrestrial carnivores (domestic dogs and wild carnivores) and bats (only in the Americas; Hanlon & Childs, 2013). Rabies virus transmitted by dogs is responsible for the majority of human deaths, accounting for up to 99% of human deaths (Bishop *et al*., 2010; Knobel *et al*., 2005; WHO, 2013).

Table 1 Taxonomy of rabies viruses (Freuling & Muller, 2013)

Species	Abbreviation	Potential vectors/reservoirs	Distribution
Rabies virus	RABV	Carnivores (worldwide); bats (Americas)	Worldwide (except several islands and peninsulas)
Lagos bat virus	LBV	Frugivorous bats (*Megachiroptera*)	Africa
Mokola virus	MOKV	Unknown	Sub-Saharan Africa
Duvenhage virus	DUVV	Insectivorous bats	Sub-Saharan Africa
European bat lyssavirus 1	EBLV-1	Insectivorous bats (*Eptesicus serotinus*)	Europe
European bat lyssavirus 2	EBLV-2	Insectivorous bats (*Myotis daubentonii, M. dasycneme*)	Europe
Australian bat lyssavirus	ABLV	Frugivorous/insectivorous bats (*Megachiroptera*/*Microchiroptera*)	Australia
Aravan virus	ARAV	Insectivorous bats (*Myotis blythi*)	Central Asia
Khujand virus	KHUV	Insectivorous bats (*Myotis mystacinus*)	Central Asia
Irkut virus	IRKV	Insectivorous bats (*Murina leucogaster*)	East Siberia
West Caucasian bat virus	WCBV	Insectivorous bats (*Miniopterus schreibersi*)	Caucasian region
Shimoni bat virus*	SHIBV	Commerson's leaf-nosed bat (*Hipposideros* commerson)	East Africa
Bokeloh bat lyssavirus*	BBLV	Natterer's bat (*Myotis nattereri*)	Europe
Ikoma lyssavirus*	IKOV	African Civet (*Civettictis civetta*)	Tanzania

*proposed species SHIBV, (Kuzmin *et al*., 2011), BBLV (Freuling *et al*., 2004) and IKOV (Marston *et al*., 2012)

Rabies in Africa

Throughout most of Africa domestic dogs plays a key role in the maintenance and transmission of RABV, accounting for the majority of reported and confirmed cases, as well as being the source of exposure for over 90% of human rabies cases. It is generally accepted that the incidence of rabies cases and resultant human deaths in Africa are underreported (Cleaveland 1998; Knobel *et al*., 2005) and that rabies surveillance systems are for the most part inadequate (Hanlon & Childs, 2013). There are concerns of re-emergence of rabies in Africa, where there is a trend of human population growth and parallel dog population growth (Cleaveland, 1998).

Traditionally rabies control measures in dogs have included mass vaccination, movement restrictions and control of stray dogs. These methods have been applied in most developed countries since the 1940s (Hampson *et al*., 2009) and have proved successful with resultant control of dog-associated rabies in many of these countries (Hampson *et al*., 2009). However, these control measures have not been as effectively applied in developed countries, where dog-associated rabies is reported to be spreading (Cleaveland 1998; Hampson *et al*., 2009; Perry, 1993).

At least 20,000 human rabies deaths per year are estimated to occur in Africa (Knobel *et al*., 2005). Table 2 is an estimate of annual human deaths due to dog-associated rabies in Africa. These data were compiled by Knobel *et al*. (2005), when they quantified the public health and economic burden of endemic canine rabies in Africa and Asia. They used data collected from the region and applied it to a set of linked epidemiological and economic models where the human population at risk from endemic canine rabies was predicted using data on dog density. They also estimated human rabies deaths from a series of probability steps to determine the likelihood of clinical rabies and death in a person after being bitten by a dog having rabies. In this article they estimated the total number of human deaths due to canine rabies in Asia and Africa as approximately 55,000 people per year.

Table 2 Estimated annual human mortality caused by dog associated rabies in Africa (Knobel *et al.,* 2005)

Model output	**Africa**	
	Rural	**Urban**
Total Population (million)	294.2	498.1
Population at Risk	294.2	340.1
No. of bites from suspected rabid dogs (thousands)	374.3	427.8
No. of rabies deaths	5 886	17 937
No. of deaths/100,000 people	2.00	3.60
No. of regional deaths	23 705	
90% probability estimates	(6 903-45 932)	

Tables 3 and 4 respectively shows data on rabies in Africa compiled from the proceedings of the Southern and Eastern Africa Rabies Group (SEARG) meetings in 1999 (Table 3) and in 2013 (Table 4).

Rabies in South Africa

Animal Rabies in South Africa

In South Africa, two RABV biotypes have been described: the mongoose and canid biotypes. These two biotypes are transmitted and maintained by members of the *Herpestidae* and *Canidae* families, respectively. The canid biotype of RABV is the most widely distributed in the world. In South Africa, RABV is maintained by dogs and black-backed jackals (*Canis mesomelas*) in the northern region of the country, by dogs in the eastern region where most cases of human rabies occur, and by bat-eared foxes (*Otocyon megalotis*) in the western region (Bingham, 2005; Gummow, Roefs & De Klerk, 2010). In addition, an indigenous herpestid biotype of RABV is transmitted by yellow mongooses (*Cynictis penicillata*) on the interior plateau of South Africa. This biotype causes occasional cases of rabies in dogs, cats, humans, and more frequently, cattle and sheep (Swanepoel, 2004).

The first confirmed case of rabies in South Africa occurred in a dog in 1893 in the Eastern Cape (Swanepoel, 2004), and was traced back to the importation of a dog from England (Bishop *et al*., 2010). In 1928 the deaths of two children due to rabies were recorded in what is now the North-West Province, and the first case of rabies in a wildlife species, the yellow mongoose, was confirmed by Herzenberg (cited in Bishop *et al*., 2010). In the 1940s dog rabies spread south of the Zambezi river into northern Namibia and by 1950 an outbreak was reported in the north of Limpopo Province in South Africa (Swanepoel, 2004) and then in Zimbabwe later that year (Bishop *et al*., 2010). A rabies outbreak was confirmed in Mozambique in 1952 and the disease spread into KwaZulu-Natal Province of South Africa in 1961. By 1968 rabies was eliminated in KwaZulu-Natal by the veterinary authorities through vaccination of dogs and culling of stray dogs (Bishop *et al*., 2010). However rabies reappeared in KwaZulu-Natal in 1976, associated with the migration of refugees from Mozambique. Since then rabies has remained endemic in that province. There is evidence for the spread of rabies from KwaZulu-Natal to south-east Mpumalanga and the Eastern Cape (Bishop *et al*., 2010).

Table 3 Rabies occurrence in eastern and southern Africa, reported in 1999

Country & year	Total Dogs tested	Percentage positive dogs	Total animal tested	Rabies prevalence	Human rabies	Vaccine cell culture		Source
						Veterinary	Humans	
Botswana (1994-1998)	-	-	1 489	68%	-	5 159 (1992-1997)	I=200 000 U=190 382/yr.	(Masupu *et al*., 1999)
Kenya (1995-1998)	-	-	364	57%	-	-	I=470 700 U=234 865	(Karugah, 1999)
Namibia (1994-1998)	127	54.3%	433	52.1%	-	-	-	(Huebschle, 1999)
South Africa (1995-1998)	-	41.1%	-		L=55	-	-	(Bishop, 1999)
Sudan (1994-1998)	52	50%	817	54.4%	L=165	-	U=7 232 (1998)	(Ali, 1999)
Uganda (1994-1998)					L=58	13 562	I=590 000 U=419637	(Rutebarika, 1999)
Zimbabwe (1997-1998)				38.6%	L=6		I=819 000 U=851 674	(Javangwe, 1999)

C: clinical; L: laboratory; I: imported; U: used

Table 4 Rabies occurrence in eastern and southern Africa, reported in 2013

Country & year	Total Dogs tested	Percentage positive dogs	Total animal tested	Rabies prevalence	Human rabies	Total dog bite	Vaccine cell culture		Source
							Veterinary	Humans	
Botswana	227	41%	417	39.33%	C=N/A L=1 (2009)	N/A	I=600000	I=38778	(Moyane, 2013)
Kenya	135	85%	350	93%	C=0 L=7	318 506 (All bites)	N/A	N/A	(Kiambi, 2013)
Namibia	546	44.8%	1 618	51%	C=0 L=1	N/A	N/A	N/A	(Kabajani, 2013)
South Africa	3 247	38.4%	5 415	12%	C=2 L=28	N/A	I=70000000 U=234900	N/A	(Shumba, 2013)
Tanzania	189	46%	241	51.5%	C=70 L=0	1 956	I=656000	U=1500	(Mpelumbe, 2013)
Uganda	19		32		C=56 L=0	50 508	I=150000 U=234900	I=40600	(Rutebarika,*et al.*, 2013)
Zimbabwe	273	71%	511	69.1%	8 (C/L not indicated)	11 959	U=450000	N/A	(Makaya, 2013)

C: clinical; L: laboratory; I: imported; U: used

Gummow, Roefs & De Klerk (2010) analysed epidemiological data on all animal rabies cases reported in South Africa for the period 1993 to 2005. They report that the majority (79%) of animal rabies cases are reported in domestic animals (companion animals and production animals). Of these, 74% are in canines and 21% in bovines. Geographically, 46% of all reported animal rabies cases in South Africa occurred in KwaZulu-Natal, of which 89% were in dogs. Eastern Cape and Mpumalanga each accounted for 15% of rabies cases in South Africa, of which 48% and 44% respectively were in dogs. An outbreak of rabies in dogs in Limpopo in 2006 coincided with a dramatic increase in human rabies cases, with 22 human cases confirmed in that year alone (Bishop *et al*., 2010).

The breakdown by species of all rabies cases diagnosed in animals from 1928 to 2006 in South Africa is shown in Table 5. Bishop *et al*. (2010) state that of the more than 300 domestic animal RABV isolates in South Africa (particularly from KwaZulu-Natal) that have been typed using monoclonal antibodies, all proved to be the canid biotype, supporting the notion that domestic dogs are the reservoir host species in the rural parts of KwaZulu-Natal, Mpumalanga and Eastern Cape. In Eastern Cape, canine rabies is reported to be the main driver of most rabies outbreaks, responsible for 52% of the total rabies cases in Eastern Capefrom 1986 through 2009 (Van Sittert *et al*., 2010).

Table 5 Rabies cases diagnosed in domestic animals in South Africa, 1928 to 2006 (Bishop *et al.,* 2010)

Domestic Animal		1928-1991	1992-2000	2001-2006	Total
Dogs	*Canis familiaris*	3 322	2 433	2 308	8 063
Cats	*Felis domesticus*	437	146	104	687
Cattle	*Bos species*	2 211	818	631	3 660
Sheep	*Aries ovis*	119	39	36	194
Goats	*Capra hirsutus*	60	74	80	214
Horses & donkeys	*Equus calabus,* *Equus asnus*	53	28	31	112
Pigs	*Suis scrofula*	25	11	6	42
Guinea pigs	*Cavia porcellus*	1	0	0	1
Total		**6 228**	**3 549**	**3 196**	**12 973**

Human Rabies in South Africa

Laboratory-confirmed human rabies cases in South Africa from 2003 through 2013 are presented in Figure 1. Weyer *et al*. (2011) recorded that 85% of laboratory-confirmed human cases in South Africa over a period of 25 years (1983-2007) have been associated with domestic dogs, with the remaining 15% are probably linked to exposure to wildlife and cats (Bishop *et al*., 2010; Dermaux-Msimang, Weyer & Paweska, 2014). A separate report states that 420 human rabies cases have been recorded in the period 1983 to 2013 (Dermaux-Msimang, Weyer & Paweska, 2014). Of these, 137 cases were recorded in the period 2003 to 2013, at an average of 12.5 cases per year. In the last two years (2012-2013) only 17 cases were recorded (Dermaux-Msimang, Weyer & Paweska, 2014).

In South Africa most victims of rabies are children under the age of 10 years, which may be attributed to their inquisitive nature, an inability to protect themselves from a rabid dog attack and their height, which makes it easy for dogs to overpower them (Bishop *et al*., 2010). Table 6 summarises the demographics of confirmed human rabies cases in South Africa, from 1983 through 2007.

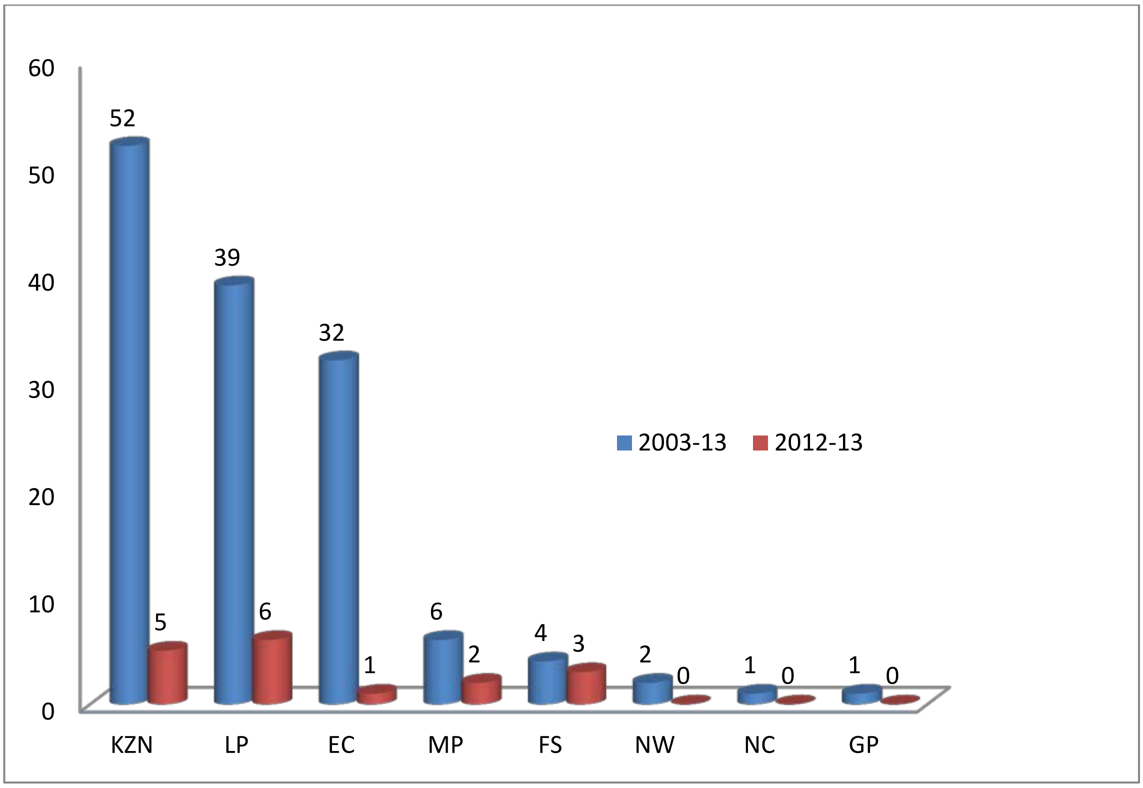


Figure 1 Laboratory-confirmed human rabies cases in South Africa by province, 2003 to 2013 (Bishop *et al*., 2010; Dermaux-Msimang, Weyer & Paweska, 2014).

KZN: KwaZulu-Natal, LP: Limpopo Province, EC: Eastern Cape, MP: Mpumalanga, NW: North West, NC: Northern Cape, GP: Gauteng Province

Table 6 Summary of the demographics of confirmed human rabies cases in South Africa, 1983 to 2007 (Weyer *et al.,* 2011)

Feature	Percentage of total
Sex	
Male	64.6%
Female	31.2%
Unreported	4.2%
Age	
Children (< 10 years)	48.8%
Young adults (11-20 years)	21.8%
Adults (> 20 years)	25.2%
Unreported	4.2%

The highest numbers of human rabies cases in the past few decades have been reported from KwaZulu-Natal and adjacent areas of the Eastern Cape (Table 7). Recently, Limpopo Province experienced a major outbreak in Vhembe District (Cohen *et al*., 2007). Later, rabies re-emerged in Mpumalanga (Mkhize *et al*., 2010) and in 2010 a human case was recorded in Johannesburg, Gauteng (Sabeta *et al*., 2013).

Rabies in Mpumalanga

Dog rabies in Mpumalanga was largely confined to the south-eastern border areas of the province adjacent to Mozambique and Swaziland, with the Nkomazi District most affected. In 2008, dog rabies spread northwards and eastwards to affect other parts of the province (Mkhize *et al*., 2010). In 2008 rabies re-emerged in Bushbuckridge Local Municipality in north-eastern Mpumalanga with confirmed cases in 105 dogs, 12 cattle, 10 goats and 1 cat (Rikotso, 2011). Mkhize *et al*. (2010) were able to trace this re-emergence to spread from Nkomazi District. According to these authors, there are two rabies cycles maintained by domestic dogs in Mpumalanga Province. Overall, these viruses belong to one viral lineage widely distributed in Mpumalanga Province, KwaZulu-Natal, Mozambique, and Swaziland.

Table 7 Laboratory confirmed cases in South Africa from 1986 to 2007 (Bishop, 1999, Weyer *et al*., 2011)

Year	Kwa-Zulu Natal	Eastern Cape	Mpumalanga	Northern Cape	Free State	North West	Limpopo	Western Cape	Gauteng	Total
1986	7	0	1	0	0	1	0	0	0	9
1987	16	1	0	1	0	0	0	0	0	18
1988	25	1	0	0	2	0	0	0	0	28
1989	10	0	0	0	0	0	0	0	0	10
1990	11	0	0	1	0	0	0	0	0	12
1991	20	0	0	0	0	0	0	0	0	20
1992	22	2	0	0	0	0	0	0	1	25
1993	21	2	0	0	1	0	0	0	0	24
1994	18	1	0	0	0	0	0	0	0	19
1995	29	0	0	0	0	0	0	0	0	29
1996	12	2	0	0	0	0	0	0	0	14
1997	3	2	0	0	0	1	0	0	0	6
1998	5	1	0	0	0	0	0	0	0	6
1999	4	2	0	1	0	0	0	0	0	7
2000	7	1	0	0	0	1	0	0	0	9
2001	6	0	1	0	0	0	0	0	0	7
2002	8	0	0	1	0	0	0	0	0	9
2003	9	1	0	0	0	1	0	0	0	11
2004	7	0	1	0	0	0	0	0	0	8
2005	3	3	0	0	1	0	0	0	0	7
2006	4	4	0	0	0	1	22	0	0	31
2007	9	4	0	0	0	0	1	0	0	14
Total	**256**	**27**	**3**	**4**	**4**	**5**	**23**	**0**	**1**	**323**

Rabies Control

Rabies in dog populations can be controlled and in certain circumstances eliminated by mass vaccination of dogs. The main goal of rabies control is to prevent the transmission of the virus to humans (Wandeler *et al*., 1988). The World Organization of Animal Health (OIE) recommends recombinant, modified live and inactivated virus vaccines, with primary vaccination of dogs from an early age up to six months and then annual boosters in endemic areas or 3-5 year boosters in non-endemic areas; thereafter it is necessary to monitor vaccination coverage in the population (Knopf, 2008; WHO, 2013). Dog rabies was endemic throughout the Unites States of America but by the 1970s a significant reduction in the number of cases had been brought about by extensive mass vaccination programmes and the effective control of stray dog populations. Dog-associated rabies was declared eliminated from the USA in 2008 (Velasco-Villa *et al*., 2008).

Implementation of mass vaccination has been successful in the control of rabies in several countries including those in western Europe and North America (WHO 2013). In sub-Saharan Africa, mass vaccination is widely used as the main tool in dog rabies control, with success recorded in areas like KwaZulu-Natal (Bishop *et al*., 2010; Le Roux, 2011), and parts of Tanzania (Cleaveland *et al*., 2003; Kaare *et al*., 2009) and Kenya (Kitala *et al*., 1993). The WHO has recommended that a 70% vaccination coverage is sufficient to reduce transmission and control rabies (Bishop *et al*., 2010; Hampson *et al*., 2009). This is to be achieved in every community through a well-designed educational and vaccination campaign. WHO also recommend that intersectoral cooperation and community participation in the vaccination process be encouraged, and that quality vaccines be used (WHO 2013).

Despite the success of mass rabies vaccination in some campaigns in the past, there are also records of unsuccessful campaigns. Kongkaew *et al*. (2004) reported that in Thailand, despite a 70% vaccination coverage obtained, rabies was not controlled due to the large number of unvaccinated stray or feral dogs (25% of the dog population are feral dogs) coming in contact with vaccinated dogs. Other reasons for the failure of mass dog vaccination programmes include:

- The lack of adequate strategies or programs that take into account the ecology of dog populations (Butler & Bingham, 2000)
- Insufficient sustainable resources (economic and human resources) to reach required vaccination levels (Lembo *et al*., 2010)
- Socio-political factors affecting vaccine procurement, especially as vaccination may be of little importance to political decision makers (Lembo *et al*., 2010)
- The planning of control programs is a management task in which geographic coverage could be a challenge as the size of the dog population must be established (Cleaveland, 1998; Lembo *et al*., 2010; Wandeler *et al*., 1988)
- Sociological factors, for example the HIV/AIDS pandemic is reported to have played a role in increasing the number of ownerless dogs roaming thereby increasing the number of unvaccinated dogs (Gummow, Roefs & De Klerk, 2010)

Furthermore, when vaccinations are administered annually in populations through 'pulse' campaigns, (Hampson *et al*., 2009) describe that the high birth and death rates recorded in African dog populations cause the total vaccination coverage to decline rapidly after a single campaign, with a high risk of disease outbreaks between campaigns. Domestic dog population turnover has a marked influence on rabies dynamics, which may explain the variable success of vaccination efforts especially in developing countries. Hence emphasis is laid on regular vaccination campaigns to maintain population level immunity. In Tanzania, for example, vaccination campaigns should be conducted once every 6-8 months to maintain population immunity above a critical threshold (P_{crit}) (Cleaveland, 1998).

Herd immunity of any population needs to be maintained at a level that can prevent sustained disease transmission, which is above the p_{crit}. This is determined by the basic reproductive rate of a disease (R_0): the average number of secondary infections produced by an infected individual in an otherwise fully susceptible population. R_0 is an important parameter in infectious disease epidemiology and considerable effort has been devoted to its estimation and to understanding its implications for disease control (Hampson *et al*., 2009). An $R_0 < 1$, means that (on average) a case will not be fully transmitted to another, and the disease will die out. Vaccination aims to reduce the effective reproduction number R_e, down to below one.

Hampson *et al*. (2009) estimate that R_0 for rabies virus is 1.3-1.7, and that the critical vaccination threshold for rabies elimination (P_{crit}) is 20-40%. For rabies, it is estimated that achieving the recommended target vaccination coverage of 70% in annual campaigns will result in levels of herd immunity remaining above p_{crit} in the period between campaigns (Hampson *et al*., 2009). This recommendation is based on demographic parameters including the population birth rate and death rate (i.e. natural rate of population change), as well as the duration of vaccine-induced immunity. For planning vaccination campaigns, it is therefore neccessary to know the size and the rate of change of the dog population since these are factors that can affect herd immunity.

Feral dogs are those that are not owned or that were previously owned but now unattended to, and are not purposely fed or sheltered by individuals in the community (Gsell *et al*., 2012). If there is a high population of feral dogs in any community, the vaccination coverage of dogs in that community will be affected. A number of studies have revealed that the populations of feral dogs in rural or urban communities in Africa are in fact not as high as initially suspected (Gsell *et al*., 2012; Kayali *et al*., 2003; Kitala *et al*., 1993), seldom accounting for more than 10% of the total dog population.

Efforts to reduce dog population numbers and high turnover rates include fertility control (e.g. surgical sterilization) and culling of dogs, sometimes in conjunction with vaccination. The intended benefits of including sterilization alongside vaccination is a reduction of dog population turnover which in turn helps to maintain herd immunity (Hampson *et al*., 2009). During sterilization campaigns several results can be achieved, including reducing the number of unowned dogs, improving the health of dogs and reducing the problem of female dogs in oestrus (Morters *et al*., 2013; Totton *et al*., 2011; Wandeler *et al*., 1988). This will reduce the chances of dogs being abandoned on the streets, although there is a probability that these dogs could be ‘adopted’ by a household. Sterilization of unowned dogs will reduce the production of offspring that are likely to also remain unowned; these dogs are at a high risk of contracting rabies (Morters *et al*., 2013).

Culling on the other hand has been shown to be ineffective in controlling rabies (Morters *et al*., 2013). In Korea and Israel for example, culling of dogs was ineffective, whereas subsequent vaccination in these countries controlled the disease (cited by Morters *et al*., 2013). Culling is still implemented in some developing countries as reported during the 1999 SEARG conference in Uganda. These countries included Kenya (Karugah, 1999), Sudan (Ali, 1999) and Uganda (Rutebarika, Ademun & Mugabi, 2013). This practice is still being used partly because of financial constraints, ease of implementation compared to annual vaccination and as a form of awareness to the public concerning rabies in dogs (Morters *et al*., 2013). Non-selective elimination of dogs (culling) to reduce the host population is no longer recommended as a strategy to control rabies (WHO 1984), because it increases population turnover and decreases herd immunity, while public opposition to dog removal can lead to the failure of rabies control campaigns (Kayali *et al*., 2003).

Demography is the scientific study of populations, especially with reference to their size, structure, distribution and changes over time (Beran, 1982, Hampson *et al*., 2007; Wandeler *et al*., 1988). In Africa, dogs are intimately dependent on humans for food and shelter, and this association means that dog populations can be correlated, in size as well as distribution, with human populations (Wandeler *et al*., 1988). The demography of dog populations has been studied in several countries (Acosta-Jamett *et al*., 2010; Bingham, 2005; Gsell *et al*., 2012; Hampson *et al*., 2007; Kitala *et al*., 1993; Knobel *et al*., 2008; Ratsitorahina *et al*., 2009; Wandeler *et al*., 1988). Understanding host demography is important in understanding the impact of control strategies on infectious diseases, such as vaccination against rabies, and to assist in making decisions in the planning and implementation of interventions for dog population control (Cleaveland, 1998; Knobel *et al*., 2008; Wandeler *et al*., 1988). Demographic parameters such as the size of dog and human populations, are important in defining the human:dog ratio (Bingham, 2005; Butler & Bingham, 2000; Gsell *et al*., 2012; Hampson *et al*., 2007; Hampson *et al*., 2009; Kitala *et al*., 1993; Knobel *et al*., 2008), how many households have dogs and how many dogs there are in each dog-owning household (Bingham, 2005, Butler & Bingham, 2000; Gsell *et al*., 2012; Hampson *et al*., 2009; Kaare *et al*., 2009; Knobel *et al*., 2008). Information on population sizes needs to be considered when planning vaccination coverage and the frequency of pulse vaccination to be conducted (Cleaveland, 1998; Cleaveland *et al*., 2003; Hampson, *et al*., 2009; Kitala *et al*., 1993). African dog populations are characterized by high birth and death rates and hence high turn-over rates. High birth rates generate a supply of susceptible animals to maintain cycles of infection. Through population growth, populations which previously could sustain only sporadic, short-lived epidemics may become large enough to maintain independent cycles of infection and act as reservoirs of rabies. Parameters such as sex ratios and the age distribution of dogs are therefore important population indices as they allow prediction of birth rates. Table 8 shows a range of demographic parameters obtained from studies of dog populations in a range of settings around the world.

A Health and Demographic Surveillance System (HDSS) is a more recent name for what was previously termed a Demographic Surveillance System (DSS), developed in 1963 in human populations (Demissie, 2001). More recently it has been developed into the International Networking for the continuous Demographic Evaluation of Population and Their Health in developing countries (INDEPTH). The DSS was developed as a major part of a field research program of the International Centre for Diarrhoeal Disease Research in Bangladesh (Demissie, 2001). This has since been recognized as the largest and longest sustained prospective longitudinal demographic and health surveillance of any population in the world. A DSS is defined as a set of field and computing operations to handle the longitudinal follow-up of well-defined entities or primary subjects (individuals, households, and residential units) and all related demographic and health outcomes within a clearly circumscribed geographic area. Unlike a cohort study, a DSS follows up the entire population of such a geographic area (Demissie, 2001). A DSS is useful in monitoring the dynamics of populations through careful and systemic collection and processing of information on births, deaths, and migrations. This study will implement a DSS for dogs in the study area covering an area in the Mnisi area, hence forth be referred to as the Demographic Surveillance Area (DSA).

Table 8 Dog demographic parameters obtained from detailed studies in a range of rural and urban settings worldwide

Country	Setting	Methodology /study type	No of dogs	Growth rate	Dog density (Dog /km²)	Sex ratio M:F	Human Population	Human /Dog	No of House-hold	Dog owing households	Dogs /households	Dogs /DOHH	Rabies vaccination coverage	Source
NORTH AMERICA														
Baja California in Mexico	Rural & Urban	Cross sectional	910			1.5		4.3-4.5	954	54% (511)	1.05	2	65%	(Flores-Ibarra M, Estrella-Valenzuela G 2004)
Mexico	Rural	Cohort study	1 597				5 426	3.4	764	74.1% (566)	2.0	1:0.35 (3dog /DOHH)	72%	(Fishbein *et al.*, 1992)
SOUTH AMERICA														
Bolivia South America	Rural	MEPI-cluster survey	542			1.4	2 486	4.6	390	77.1% (301)		1.4–1.8	85%	(Suzuki *et al.*, 2008)
Chile (Coquimbo)	Rural &	Cross sectional	1 168	9% rural	87.1 -	7.0	4 298	2.1	1 325	61% (654)	1.5	2.0		(Acosta-Jamett *et al.*, 2010)
	Urban			20% Urban				2.0		1.4		1.8		
ASIA														
India	Rural & Urban	Multi-centric rabies Survey	1 458			1.5	52 731	3.6	8 500	16.8% (1436)			33%	(Sudarshan *et al.*, 2006)
Thailand	Urban	MEPI-cluster survey	375		-	2.0	1 742	4.6	403	54% (218)		1.7	78%	(Kongkaew *et al.*, 2004))

Country	Setting	Methodology /study type	No of dogs	Growth rate	Dog density (Dog /km^2)	Sex ratio M:F	Human Population	Human /Dog	No of House-hold	Dog owing households	Dogs /households	Dogs /DOHH	Rabies vaccination coverage	Source
AFRICA														
Kenya	Rural & peri-urban	Cohort study		9%	110 peri 6-20 rural (Av-14		1.5:1	1:7.7		63%	1.4	2.1	-	(Kitala *et al.*, 2001)
Madagascar	Urban (Antananarivo)	Cross sectional	2 454			1.5	10 698	4.9	1 541	88.9% (1370)		1.4	35.6% (< 40%)	(Ratsitorahina *et al.*, 2009)
Tanzania	Rural and Urban	Cross sectional			-	-	-	12.3	1 471	16.4-23.9% Av-14% (202)	2.0	2.38		(Knobel *et al.*, 2008)
Tanzania	Agro-pastoral	Cross sectional	1 597		> 10		11 598	7.26		1:10	1.2		80.3%	(Kaare *et al.*, 2009)
	Pastoral		692		< 5		5 222	7.55		2.14			19.2%	
Tanzania	Rural Agro pastoral-Serengeti	Cross-sectional	Approx. 802	Tanzania 0.88% BUT Serengeti 9%	9.38	0.43	Human growth rate@ 2.6% /yr.	-	-	-	-	-	55%	(Hampson *et al.*, 2009)
	Rural Pastoral Ngorongoro			10.2%	1.36		3.8% /yr.	-	-	-	-	-	80%	
Tanzania	Urban Iringa	Cross sectional	2 498	10%	334	1.4	34 162	14	7 993	13.2% (1063)	0.31	2.4	77.8%	(Gsell *et al.*, 2012)
Zimbabwe	Agro-pastoral Rural /communal lands	Cross sectional	1 085	6.52%	20.9	1.3	5 055	4.7	705	437	1.5	2.5		(Butler & Bingham 2000)

AV: average; DOHH: dog-owing household; F: Female; HH: Household; M: Male; MEPI: Multi-expanded program on immunization; NOHH: Non- dog-owing household

Aims and Objectives

The aim of this study was to determine the demographic parameters, including the annual growth rate, of an owned dog population in a rabies-affected area of South Africa.

Specific objectives were to determine the following demographic parameters for the population, through repeat census at two time points:

- size and density of the population
- proportion of households that are dog-owning
- mean number of dogs per dog-owning household
- human:dog ratio in the study area
- dog population sex ratio
- population age structure
- proportion of dogs that are vaccinated against rabies
- proportion of dogs that are surgically sterilized

The final objective is to explore differences in the above parameters between the two time points.

Chapter 3:
Materials and methods

Study area

This study took place within the site of a health and demographic surveillance system in dogs (HDSS-Dogs) in Hluvukani settlement, Bushbuckridge Local Municipality, Mpumalanga Province, South Africa (Figure 2). Bushbuckridge has an estimated human population of 537,725, a population density of 1,969 people/km^2, and an annual population growth rate of 0.79% (Stats SA, 2012). Hluvukani settlement, in the north-eastern part of Bushbuckridge, comprises two administrative areas: Claire B and Eglinton A villages. The boundaries of the demographic surveillance area (DSA) were defined prior to the start of the study (Figure 3).

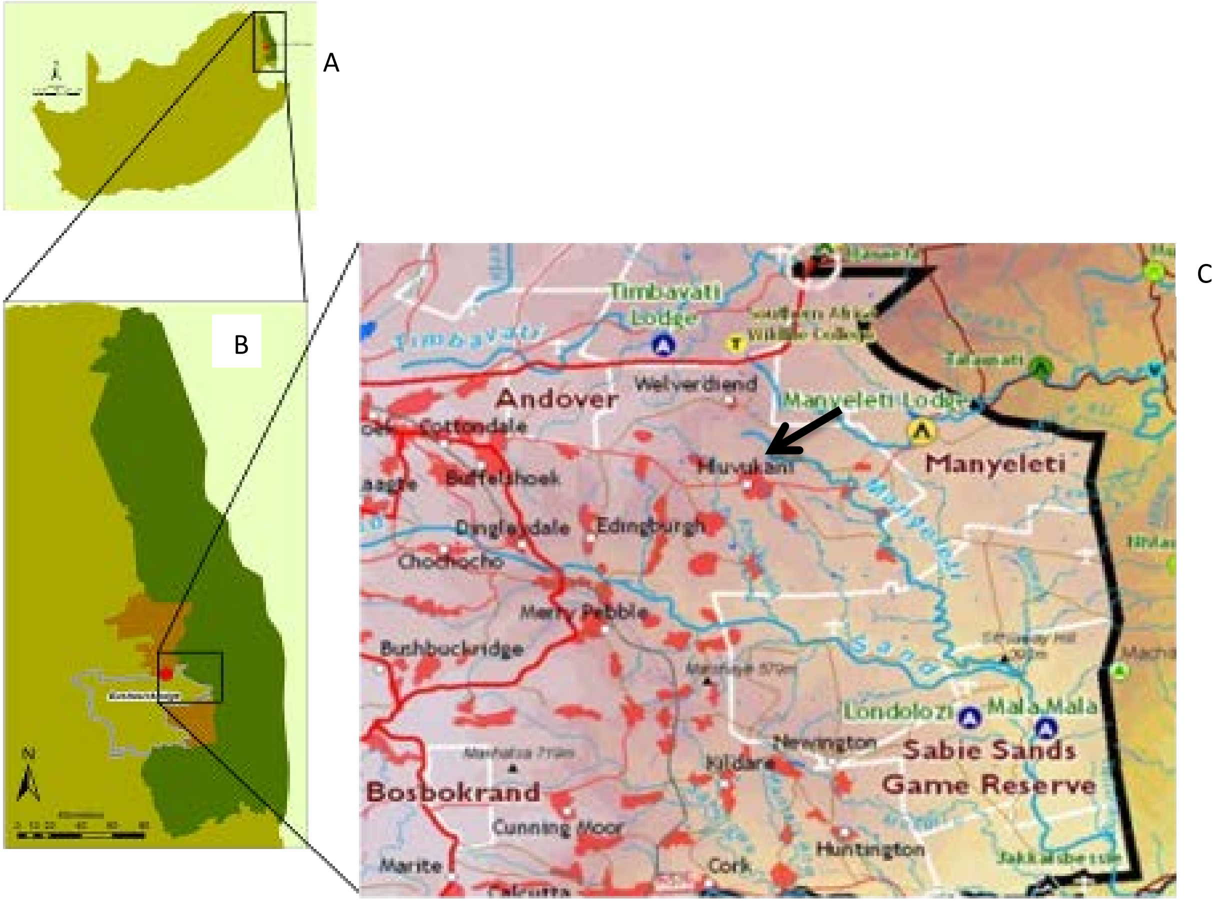


Figure 2 Map showing the Hluvukani study area: A) Position of the demographic suveillance area (DSA) in the north-eastern part of South Africa. B) The position of the DSA in Bushbukridge Municipality (doted line) at the border of the Kruger National Park (dark green). C) Location of Hluvukani (arrow) in Bushbukridge Municipality

Figure 3 Demographic surveillance area (DSA) and location of households in Hluvukani, Mpumalanga, 2013. The black dots refer to all stands included in the DSA during the first census.

Study design and data collection

Two complete censuses of the owned dog population in the DSA were done for this study. The first census took place from July 2011 through October 2011. The second census took place from May 2013 through October 2013. Initially, a map of the study area was obtained and all households identified with unique numbers assigned by the study team (Appendix 1). Later, permanent identification numbers were assigned to most of the households by the municipality ('stand numbers'), and all households were geo-referenced by the study team.

All households that could be located and identified were visited by study teams during the censuses, and data collected through a structured questionnaire (Appendix 2). In the first census, data were collected by two study teams comprising research assistants, final-year veterinary students from the University of Pretoria and animal health technicians from the Mpumalanga Veterinary Services. During the first census, rabies vaccine was administered at the households to all unvaccinated dogs that could be caught and restrained. Data were collected using SurveyToGo software (version 1.32.110, Dooblo®) on handheld personal digital assistants (PDAs), and uploaded into a Microsoft Excel spreadsheet. During the second census, data were collected by a single study team comprising two research assistants, using open-source data collection software on mobile phones (Open Data Kit on Samsung Galaxy® tablet), and uploaded in Comma Separated Values format. All databases were linked in a single dataset with R (R Foundation for Statistical Computing, Vienna, Austria, www.R-project.org). Geographic coordinates were captured using a hand-held GPS (GPS 60, Garmin) and analysed with ArcGIS 10® (ESRI). All owned dogs that could be caught and restrained were identified by implanting microchips (Backhome Biotech, Virbac) subcutaneously midway between the scapulae (Figures 4 and 5). A Virbac V500 scanner was used to detect and read implanted microchips. Dogs were also photographed and the microchip number of each dog was saved with its picture (Figure 6). If a dog could not be restrained for microchip implantation, a unique code including the house number, the name and the sex was given to the dog.

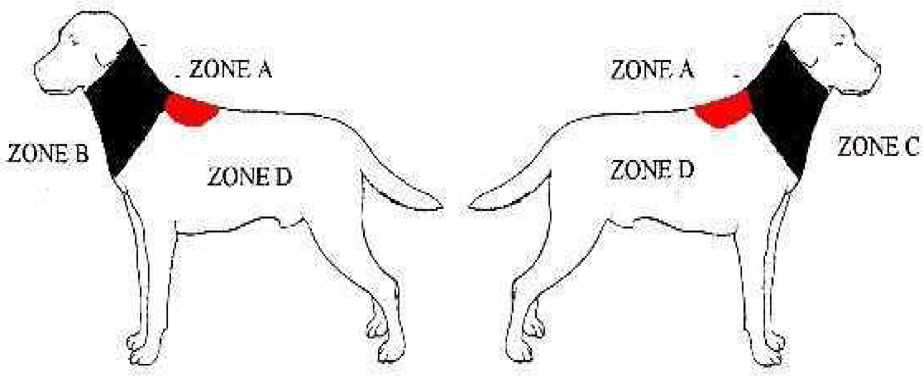
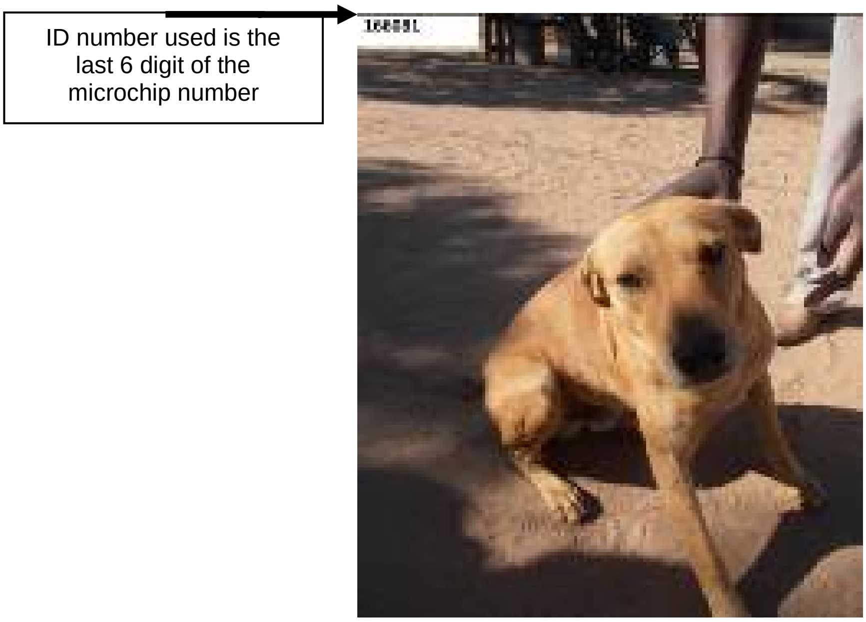


Figure 4 Recommended sites for microchip implant for dogs and cats (Springs & Peacock 2011) is in the middle of Zone A - in red. However Zone B, C and D must be scanned before microchip implantation to avoid repetition.

Figure 5 Microchip implantation in a dog



ID number used is the last 6 digit of the microchip number

Figure 6 Photo identification of dog

Data were collected at a household level (number of dogs and, for the second census only, number of people in the household) and at an individual dog level (name, age, sex, rabies vaccination history, surgically sterilized or not). Although not part of this study, data on dog entry (birth, in-migration) and exit (death, out-migration) events in households were recorded by the HDSS-Dogs during repeat visits in the period between the two censuses (three visits took place: November 2011 to April 2012, May to August 2012, and October 2012 to February 2013). Information on dogs collected during these repeat visits was included for the first census if the dogs were reported to have entered the household prior to the first census, but were not recorded during that census. This may have happened if households were missed by study teams (due to an incomplete map) or if owners were not at home at the time of the first census (and information on dog numbers could not be obtained from neighbours). Data presented below for the first census therefore includes this supplementary information on household and dog numbers. For the second census, if the owner was not home, any dogs recorded as present in the most recent visit were considered still present. Descriptive statistics were performed on data of the two censuses with the software R.

Ethics

The protocol 'A Health and Demographic Surveillance System for Dogs in a Rabies-Infected Area in South Africa' (V033/11) was approved by the Animal Ethics Committee of the University of Pretoria. Informed consent to participate in the study was obtained from a member of each household who was at least 18 years of age, and who played a role in the care of any dogs owned. This was achieved using a consent form that was translated into the local language, Xitsonga (Appendix 3). To avoid any language misunderstanding before deployment, this was back-translated to English and then retranslated to Xitsonga.

Chapter 4:
Results

Human population

The DSA covered an area of 10.4 km^2 (Figure 3). In the first census, 1,907 households in the DSA were visited and in the second census, 1,939 households were visited. The number of people per household was recorded from 1,822 households during the second census (missing data from 117 households). The total number of people in these households was 8,922 (median: 5, interquartile range: 3-7). Using the mean household size of 4.9 to infer data for the 117 missing households gives an estimate of the total human population in the DSA during the second census of 9,500 at a density of 913 people/km^2.

Dog population

The number of owned dogs recorded was 799 in the first census and 870 in the second census. The density of the owned dog population in the DSA was 76.8 dogs/km^2 in the first census and 83.7 dog/km^2 in the second census. In the second census, 655 dogs were recorded in the 1,822 households for which data on human occupants were also available (8,922 people). This gives a ratio of dogs to people of 1:14. Household indicators of the dog population recorded during the two censuses are presented in Table 9. There was no significant difference between the two periods in the mean number of dogs per household (p = 0.4), the percentage of dog-owning households (p = 0.5) or the mean number of dogs per dog-owning household (p = 0.6). The location of dog-owning households is shown in Figure 7.

Table 9 Household indicators of the owned dog population in Hluvukani, Bushbuckridge recorded during two censuses (2011 and 2013)

	First census	Second census	p-value (t-test)
Number of households	1 907	1 939	
Number of dogs	799	870	
Mean (std dev) dogs per household	0.41 (1.08)	0.44 (1.16)	0.4
Number of dog-owning households	393	416	
Percentage of dog owning households	20.6%	21.5%	0.5
Mean (std dev) dogs per dog owning household	2.03 (1.56)	2.09 (1.71)	0.6

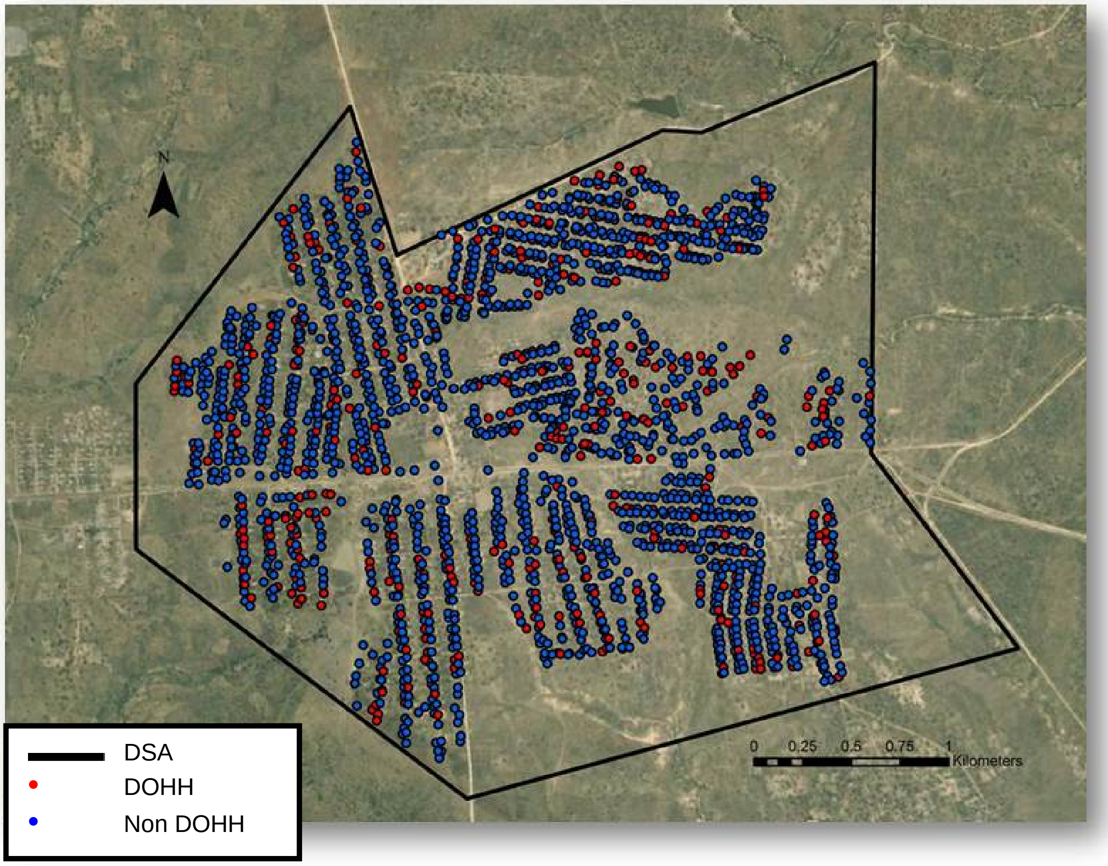


Figure 7 Map of Hluvukani, Bushbuckridge, 2013; indicating the location of non-dog owning households (blue dots) and dog-owning households (DOHH, red dots)

Dog population growth

The increase of 71 dogs between the first and second census represents an 8.9% increase in population size over the 18 months between the two counts. This equates to an annual population increase of 5.9%. The number of dog-owning households increased by 23 (5.9%). Using the mean number of dogs per dog-owning household from the second census (2.09) shows that more than half (48/71) of the increase in the dog population can be attributed to an increase in the number of dog-owning households. The remaining increase (23/71) can be attributed to an increase in the mean number of dogs per dog-owning household, from 2.03 to 2.09.

Dog population demographics

The dog population sex ratio was strongly male-biased during both the first (1.32 males per female) and the second (1.47 males per female) census. The population sex ratio was not significantly different between the two periods (chi-square test, $p = 0.3$). The population age distribution during the two censuses is shown in Table 10. The age distribution of the population differed significantly between the two time periods (chi-square test, $p < 0.05$).

Table 10 Age distribution of dogs in Hluvukani, Bushbuckridge during the first (2011) and second census (2013)

	First census	Second census
< 1 year	294 (36.8%)	210 (24.1%)
1-2 years	288 (36%)	324 (37.2%)
3-4 years	146 (18.3%)	198 (22.8%)
≥ 5 years	39 (4.9%)	103 (11.8%)
Unknown age	32 (4%)	35 (4%)

Vaccination coverage and sterilization

The vaccination history of dogs recorded during the first census showed that only 156/799 had been vaccinated previously (vaccination coverage: 19.5%). During the first census, a house-to-house vaccination campaign was conducted together with the census. Following this campaign, the vaccination coverage increased to 68.2% (545/799 dogs vaccinated at least once within the past three years). Vaccination coverage was 59% at the time of the second census (513/870 dogs vaccinated at least once within the past three years).

The number of dogs sterilized was low, with only 10 dogs reported as sterilized in the first census, and 12 in the second census.

Chapter 5:
Discussion

The aim of this study was to describe demographic parameters of an owned dog population in Bushbuckridge Local Municipality, Mpumalanga Province, South Africa, over two time periods. During this study, two household censuses were conducted and the results compared. From these data, demographic patterns are compared with similar studies in other parts of sub-Saharan Africa.

In this study a dog density estimate of 77 dogs/km^2 was recorded in the first census. This increased to 84 dogs/km^2 in the second census. Densities of owned dogs largely reflect human population densities, and are therefore generally higher in urban than in rural areas (Table 8). For example, Acosta-Jamett *et al*. (2010) reported dog densities ranging from 1,380 to 1,509 dog/km^2 in cities, from 119 to 1,544 dog/km^2 in towns, and from 1 to16 dog/km^2 in rural areas of the Coquimbo region of Chile. Kitala *et al*. (2001) recorded densities of 110 dogs/km^2 in a peri-urban area in Kenya, compared to densities of between 6 and 21 dogs/km^2 in a nearby rural district. In Zimbabwe, Brooks (1990) and Butler & Bingham (2000) recorded densities of 68 dogs/km^2 and 6 dogs/km^2 in an urban and a rural area, respectively. Gsell *et al*. (2012) recorded a density of 334 dog/km^2 in an urban area in Tanzania. Although Wandeler *et al*., (1988) recorded 1,700 per km^2 in one rural area of Sri Lanka, this was attributed to the high human population density of the area.

The ratio of people per dog seems more consistent across settings in sub-Saharan Africa. The human:dog ratio of 14:1 obtained in this study is similar to estimates of 11 from a village in North West Province, South Africa (Rautenbach, Boomker & De Villiers, 1991), 15 in rural Machakos District, Kenya (Kitala *et al*., 2001), 14 in urban Iringa, Tanzania (Gsell *et al*., 2012), and an overall estimate of 14 across 12 sites in urban and rural Tanzania (Knobel *et al*., 2008). However, studies in other settings have recorded much lower human:dog ratios. In general, American and European countries report a human:dog ratio of between 10:1 and 6:1 respectively (Wandeler *et al*., 1988). Other studies have estimated a ratio of around 5 in urban Thailand (Kongkaew *et al*., 2004), urban Madagascar (Ratsitorahina *et al*., 2009) and urban Mexico (Flores-Ibarra & Estrella-Valenzuela, 2004). Reliable estimates of human population sizes can be derived from census data or household surveys (Butler & Bingham, 2000; Hampson *et al*., 2009). It has been recommended that human:dog ratios obtained from detailed studies in a range of rural and urban settings can be used as a preliminary guideline of the number of owned dogs for planning purposes for mass dog rabies vaccination programmes (Lembo *et al*., 2010).

The number of dogs per household in this study (0.40-0.44) is similar to the estimate of 0.31 in urban Tanzania (Gsell *et al*., 2012), but substantially lower than other estimates from sub-Saharan Africa (1.2 in agro-pastoral Tanzania, Kaare *et al*., 2009; 1.4 in rural Kenya, Kitala *et al*., 2001; 1.5 in communal lands in Zimbabwe, Butler & Bingham, 2011) and elsewhere (1.5 in rural Coquimbo, Chile, Acosta-Jamett *et al*., 2010; 2.0 in rural Mexico, Fishbein *et al*., 1992). Estimating the number of dogs in an area from the number of households may therefore provide less accurate estimates of dog numbers, not least because of the difficulties in determining the total number of households in a given area.

A total of 393 (20.6%) households reported owning a dog in the first census. This increased to 416 (21.45%) households in the second census. More than half of the increase in the total dog numbers in the study site can be attributed to an increase in the number of dog-owning households. The percentages of DOHH recorded in this study are higher than other estimates recorded in India (16.89%; Sudarshan *et al*., 2006), and Tanzania, where Gsell *et al*. (2012) reported a percentage DOHH of 14%. Knobel *et al*. (2008) recorded a similar percentage in their study, with a range from 16.4% to 23.9%. By contrast, estimates from other studies are higher than what we have recorded, including 74.1% in a rural area (Fishbein *et al*., 1992) and 54% in an urban area (Flores-Ibarra & Estrella-Valenzuela, 2004) in Mexico, 54% in an urban setting in Thailand (Kongkaew *et al*., 2004) and 77% in rural Bolivia (Suzuki *et al*., 2008).

The mean number of dogs/DOHH in Hluvukani was 2.03 in the first census and 2.09 in the second census. This is similar to records across sub-Saharan Africa, including estimates of 2.1 in Kenya (Kitala *et al*., 2001), 2.4 in urban Tanzania (Gsell *et al*., 2012), 2.4 in a rural setting in Tanzania (Knobel *et al*., 2008), 1.8 in a rural setting in Bolivia (Suzuki *et al*., 2008) and 2.0 in the communal lands of Zimbabwe (Butler & Bingham, 2000).

The increase in the average number of dogs per DOHH between the first and second census is 0.06, which explains one part of the growth in the number of dogs in the entire study area. The dog population in the study area increased between 2011 and 2013. This could be attributed to several factors. Butler & Bingham (2000) and Gsell *et al*. (2012) commented that communal land dogs are largely unsupervised: although they are fed regularly by their owners and other members of the community, they are unrestricted, receive little veterinary attention, and their reproduction is not monitored or controlled (Gsell *et al*., 2012). The pattern of dog population size and management in our study area is consistent with rural areas of other sub-Saharan African countries such as Tanzania (Gsell *et al*., 2012) and Kenya (Kitala *et al*., 2001). Even if mortality is high within the dog population, the surviving dogs will have better access to available resources and hence life expectancy of surviving dogs will increase, although there is growing evidence that dog population sizes are not regulated by environmental resource constraints but rather by human demand (Morters *et al*., 2013). By design, this study only considered the demographics of the owned dog population in the study area. There is increasing evidence that most (> 90%) free-roaming dogs in communities in Africa are owned (Butler & Bingham, 2000; Cleaveland, 1998; Gsell *et al*., 2012; Kayali *et al*., 2001).

The owned dog population in the study site showed an annual growth rate of 5.9% in the period between the two censuses. The growth rate in this study is lower than estimates recorded from other studies, with growth rates of 9% and 20% reported in rural and urban areas in Chile, respectively (Acosta-Jamett *et al*., 2010). Gsell *et al*. (2012) recorded a 10% annual growth rate in an urban area of Tanzania, and Butler & Bingham (2000) recorded a 6.5% growth rate in rural communal lands in Zimbabwe. Also in Tanzania, a growth rate of 9% was recorded in an agro-pastoral community in Serengeti while a growth rate of 10% was recorded in a pastoral setting (Hampson *et al*., 2009). Notably, all these estimates are derived using data from cross-sectional studies to determine growth rates indirectly using age-structured models. For example, Gsell *et al*. (2012) projected the growth rate by means of a Leslie matrix based on female fecundity under the assumptions that the environment remained constant, and that, given the present age distribution, the measured survival and fecundity were fixed and independent of the population size, while Butler & Bingham (2000) projected the growth rate using Caughley's method based on age distribution.

There is a predominance of male dogs in the population, which is consistent with estimates from other studies such as in urban Tanzania where a sex ratio of 1.4 males per female was recorded by Gsell *et al*. (2012), and in rural Mexico where a ratio of 1.5 males per female was recorded by Flores-Ibarra & Estrella-Valenzuela (2004). In rural Bolivia in South America an estimate of 1.4 males per female was recorded by Suzuki *et al*. (2008) and in rural India through a multi-centric survey an estimate of 1.5 males was recorded by Sudarshan *et al*. (2006). This predominance of male dogs appeared to be linked to the value associated with male dogs.

The dog population was young in the first census, with 73% of the dogs less than three years old. The proportion of young dogs was lower in the second census at 61%. This could be attributed to differences in age-specific mortality rates, or due to seasonal effects on birth and/or mortality rates (Butler & Bingham, 2000). The change in age structure may be an indication of a high turnover of dogs in the study area. This will have an effect on the vaccine-induced herd immunity against rabies of the dogs in this community (Hampson *et al*., 2009). Before this study, vaccination coverage against rabies was low (19.5%). During the first census 407 dogs were vaccinated, which increased the vaccination coverage to 68.2%. Vaccination coverage was 59% at the time of the second census. The coverage achieved in the campaign in 2011 is close to the WHO-recommended target of 70%. Coverage remained above the critical threshold of 40% (Hampson *et al*., 2009), due to a second vaccination campaign by the veterinary services in 2013. This highlights the need for annual campaigns to maintain the level of rabies vaccination coverage above the critical threshold in the study area. The 19.5% vaccination coverage (before the study) is similar with other estimates recorded in numerous rural settings such as in rural Tanzania where a vaccination coverage of 19.2% was recorded by Kaare *et al*. (2009), 33% recorded in rural parts of India by Sudarshan *et al*. (2006) and 35% recorded in Madagascar (Ratsitorahina *et al*., 2009).

During this study very few dogs were reported to be spayed or castrated. The very low number of sterilized dogs may indicate a lack of awareness of the usefulness of sterilizing dogs. The cost of sterilization may also be prohibitive in rural areas. The University of Pretoria Animal Health Clinic in Hluvukani performed the vast majority of the sterilization of the dogs in the study area (Dr G Simpson, personal communication). This is a subsidised service that is not available to the majority of dog owners in rural areas in South Africa, where the rates of sterilization are expected to be even lower (e.g Rautenbach, Boomker & De Villiers; 1991).

This study measured the demographics of the owned dog population in the DSA at two time periods, approximately 18 months apart. Although the results show an increase of 8.9% in the population between the two periods, this does not imply that growth was consistent in the intervening period, nor can predictions be made on the future growth of the population based on this study. Data from the larger HDSS-Dogs study, including the three visits conducted in the period between the two censuses presented here, will be needed to better understand the dynamics of this dog population.

Conclusion

The demographic parameters of this owned, free-roaming dog population are similar to those from other populations in semi-rural areas in Africa. The population was biased towards younger dogs (≤ 2 years old) and male dogs. The population was substantially larger at the time of the second census, mainly due to an increase in the number of dog-owning households. A house-to-house rabies vaccination campaign was able to achieve a coverage of 68.2%, close to the WHO-recommended target of 70%.

Chapter 6:
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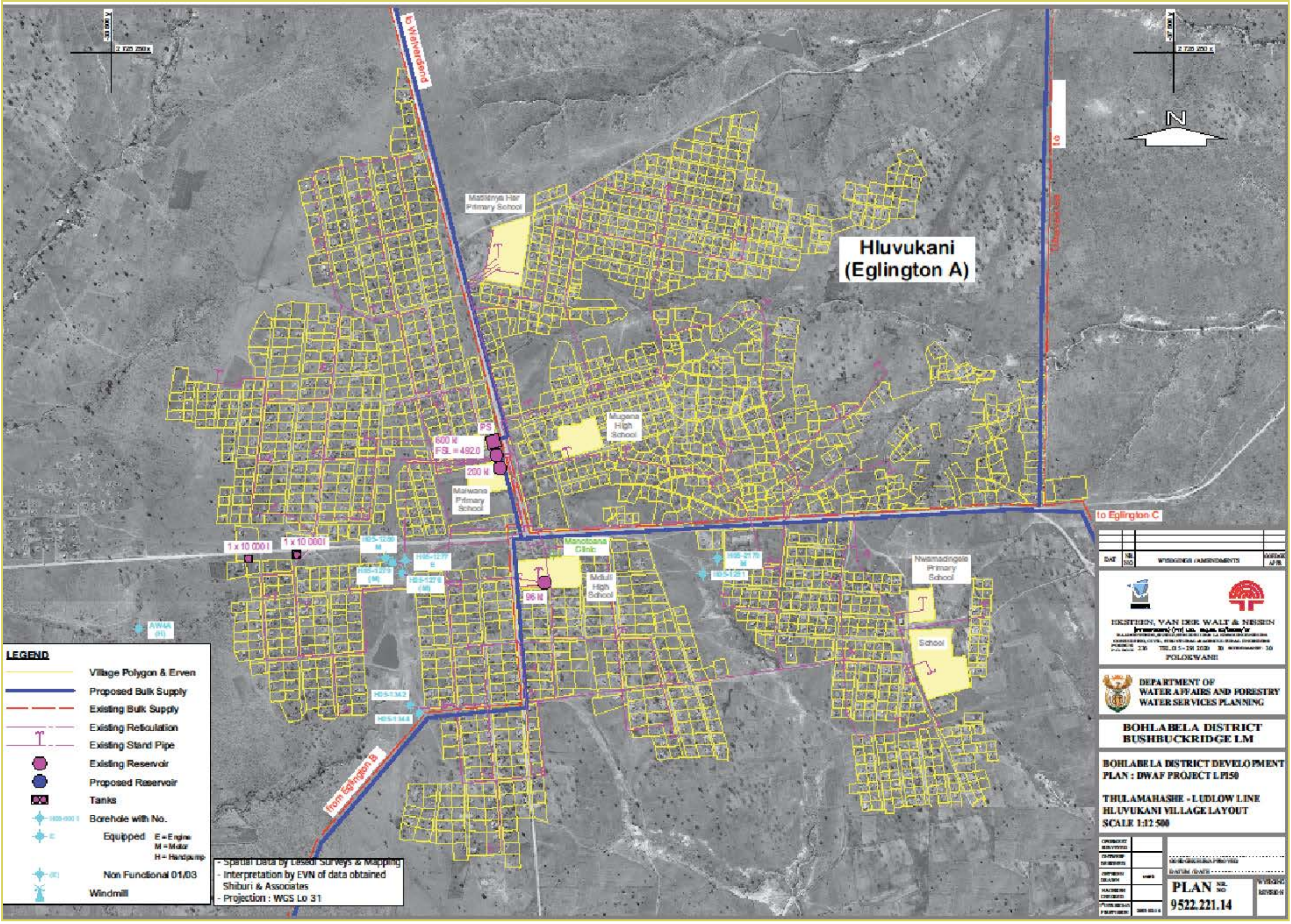
Appendix 1:
Map of the study area with uniquely assigned numbers



Appendix 1: Map showing households in the Hluvukani DSA, marked by yellow boxes. Unique household numbers ranging from 1 to 2006 were used to mark the yellow boxes.

Appendix 2:
Data collected through a structured questionnaire

HDSS-Dogs-Jun-17

Baseline survey for HDSS-Dogs
Organization: **ITMA**
Report Date: **2011/06/23 02:36:37 PM**

Question ID	Question	Answer
1	Property ID	
2	How many households live on the property?	
3	Are any dogs kept (resident) on the property?	Yes No Don't know
4	How many DOGS are kept on the property?	
5	How many CATS are kept on the property?	

Dogs Iteration 1

Question ID	Question	Answer
6	Name of dog	
7	Microchip number	
8	Was the microchip successfully implanted?	Yes No Don't know
9	Is the dog male or female?	Male Female Don't know
10	Is the dog sterilized?	Yes No Don't know
11	Aside from today, when was the dog last vaccinated against rabies?	Never vaccinated 0-12 months ago 13-24 months ago 24-36 months ago > 36 months ago Don't know
12	Was the dog vaccinated against rabies today?	Yes No Don't know
13	Date of birth of dog	
14	Precision	Day Week Month 3 months 6 months One year Two years More than two years

Dogs Iteration 2

Question ID	Question	Answer
6	Name of dog	
7	Microchip number	
8	Was the microchip successfully implanted?	Yes No Don't know
9	Is the dog male or female?	Male Female Don't know
10	Is the dog sterilized?	Yes No Don't know
11	Aside from today, when was the dog last vaccinated against rabies?	Never vaccinated 0-12 months ago 13-24 months ago 24-36 months ago > 36 months ago Don't know
12	Was the dog vaccinated against rabies today?	Yes No Don't know
13	Date of birth of dog	
14	Precision	0-3 months 4-6 months 6-One year Two years More than two years

Dogs Iteration 3

Question ID	Question	Answer
6	Name of dog	
7	Microchip number	
8	Was the microchip successfully implanted?	Yes No Don't know
9	Is the dog male or female?	Male Female Don't know
10	Is the dog sterilized?	Yes No Don't know
11	Aside from today, when was the dog last vaccinated against rabies?	Never vaccinated 0-12 months ago 13-24 months ago 24-36 months ago > 36 months ago Don't know
12	Was the dog vaccinated against rabies today?	Yes No Don't know
13	Date of birth of dog	
14	Precision	0-3 months 4-6 months 6-One year Two years More than two years

Appendix 3:
Consent form in English (Also translated into Xitsonga)

Consent to participate in a research study

Health and demographic surveillance of dogs

Researchers:	Dr Darryn Knobel	Dept. Veterinary Tropical Diseases	072 754 3243
	Dr Greg Simpson	Hluvukani Animal Health Clinic	073 443 8518
	Dr Oluyemisi Akerele	Mpumalanga Veterinary Services	082 781 8937

We are from the University of Pretoria and the Mpumulanga State Veterinary Services. We would like to do a research study in your village. The purpose of this study is to find out how many dogs there are in this village, and to study how the dog population changes in the area over the next two years. We will do this by using a dog census form, and updating the number of dogs that are born, die, or move into or out of the village.

You are being asked to participate in this study because the information is important to assist the government and other interested bodies to properly control rabies in Bushbuckridge. Rabies is carried by dogs and people may get the disease if they are bitten by a sick dog. Rabies can be prevented from spreading in the community by vaccinating the dogs. This study will tell us how many dogs must be vaccinated to control rabies.

We are approaching all households in your village to take part in this study, whether they have a dog or not. We now ask if you would like to be a part of the study. The study will continue for two years. With your permission, we will visit you every three months, and ask if you have a dog. If you have a dog, we will ask you some questions about the dog. The questions will take about 20 minutes to answer. If you have a female dog, we will visit you every six weeks so that we can find out more about her breeding.

If you have a dog, we would like to ask permission to inject a microchip under your dog’s skin, and to collect a sample of blood and faeces. A microchip is an electronic tag that will allow us to identify your dog. It will not harm your dog, but the injection will cause brief pain. Very rarely the place where the dog was injected may become infected. We will do our best to prevent this by using a new needle for every dog, and by cleaning the place well. If the place where we gave the injection does become infected, we will treat it at no cost to you. There are no direct benefits to you, your family or your dog (if you have one) if you participate in this study. Your participation will help us to understand how we can better control rabies through vaccination, thereby improving the health and welfare of dogs and people in the community.

You are free to decide if you want to participate in the study or not. If you do decide to participate today, but change your mind later, you are free to leave the study at any time without any consequences to you or your family.

If you have any questions about this study, you should feel free to ask them now or anytime throughout the study by contacting Dr Darryn Knobel (Senior lecturer, University of Pretoria, Department of Veterinary Tropical Diseases) at 072 754 3243, or Dr Greg Simpson (Hluvukani Animal Health Clinic) at 076 235 5128. If you believe that your rights have been violated in any way, please contact Dr O A Akerele on 082 781 8937. By signing this consent form, you are indicating your consent to participate in this study.

Signature ____ Date ____________