pISSN 1229-845X, eISSN 1976-555X
J. Vet. Sci. (2012), **13**(3), 293-298
http://dx.doi.org/10.4142/jvs.2012.13.3.293
Received: 19 Aug. 2011, Revised: 30 Nov. 2011, Accepted: 25 Mar. 2012

JOURNAL OF
Veterinary Science

Original Article

The effect of seasonal variation on anthrax epidemiology in the upper Zambezi floodplain of western Zambia

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Anthrax has become endemic throughout the upper Zambezi floodplain located in the Western Province of Zambia over the recent years. To date, no comprehensive study has been carried out to determine whether recurrence of anthrax outbreaks may be linked to differences in precipitation and human activities. Retrospective data for the period 1999 to 2007 showed that a total of 1,216 bovine cases of anthrax were reported. During the same period, 1,790 human anthrax cases and a corresponding case fatality rate of 4.63% (83/1,790) was documented in the upper Zambezi floodplain. Occurrence of human cases was highly correlated with cattle outbreaks ($r = 0.94$, $p < 0.001$). Differences in precipitation were significantly associated with the occurrence of anthrax outbreaks ($\chi^2 = 4.75$, $p < 0.03$), indicating that the likelihood of outbreaks occurring was higher during the dry months when human occupancy of the floodplain was greater compared to the flooding months when people and livestock moved out of this region. Human dependency on the floodplain was shown to significantly influence the epidemiology of anthrax in the upper Zambezi floodplain of western Zambia. Methods for mitigating anthrax outbreaks by disrupting the cycle of transmission are herein highlighted.

Keywords: anthrax, epidemiology, floodplain, Zambezi

Introduction

Zambia is a sub-Saharan African country located south of the equator. The human and cattle populations of this country are estimated at 12.5 million and 2.9 million, respectively. Anthrax is hyper-endemic in Zambia. Although outbreaks of this disease have occasionally been reported from different parts of the country [20-22], the number of anthrax cases has increased to alarming levels in recent years [17]. Central to the persistence of anthrax in soil is the ability of *Bacillus* (*B.*) *anthracis* to form highly resistant spores that survive in the environment for a long time [2,5]. In Zambia, previous studies have shown that clostridia infections [11] and anthrax outbreaks [17] are higher in the Western Province and Luangwa valley [20,21] than the rest of the country. Elsewhere, disease persistence and recurrence of anthrax outbreaks have been linked to various ecological factors such as cycles of heavy rainfall followed by periods of dry weather [3,4], the presence of calcareous soils [8,13], high evaporation potential of flood water [3], and ambient temperatures above 15.5°C [9]. Similarly, the upper Zambezi floodplain has a cyclic rainfall pattern with a high evaporation potential and is characterized by calcareous soil [24,25]. However, there no ecological study linking these factors to

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recurrence of anthrax outbreaks in the area has been performed.

Some studies have shown that recurrence of anthrax outbreaks is a cyclic and often influenced by activities of susceptible host animal inhabiting areas endemic with anthrax spores [3,4,10]. Other scientists have demonstrated that haemophagic flies, such as tabanids and hippoboscids, play an important role in the transmission and spread of anthrax [7,15]. Davies [1] determined that tabanids were major vectors for the transmission of anthrax during the severe widespread epidemic of 1978 ~ 1979 in neighboring Zimbabwe. Given the increased frequency of anthrax outbreaks in the upper Zambezi floodplain [17], we wanted to determine whether these outbreaks followed a seasonal trend, and assess the link between activities of the local inhabitants on the floodplain and anthrax outbreak recurrence. We also wanted to find out whether outbreaks among humans correlated with ones occurring in livestock.

Materials and Methods

Study area

The upper Zambezi floodplain lies in the Zambezi basin ($14^o19'$ ~ $16^o32'$S and $23^o15'$ ~ $23^o33'$E). It is about 1,000 m above sea level and consists of a low laying flat plateau with the plain main body covering about 5,500 km^2. The maximum flooded area is estimated to be 10,750 km^2 when flooding of all Zambezi river tributaries is taken into account, and was found to have the capacity to hold up to 17×10^9 m^3 of water during the peak of the flooding in April [16]. The floodplain stretches from the confluence of the Lungwebungu river with the Zambezi river in the north and extends south for a distance of 250 km up to the Ngonye falls. Soil of the floodplain is composed of Kalahari sand several meters deep over a layer of calcareous rock [24,25]. Because the seasonal flooding prevents tree growth, the floodplain is covered by open savannas that serve as the main source of food for livestock in the Western Province [18]. Flooding begins in the northern region in December to January, peaks in March or April in the central region, and gradually subsides in the southern region around May. Apart from runoff from the surrounding uplands, flooding is as a result of effluents from the Kabompo, Luanginga, and Lingwebungu rivers that pour into the Zambezi in the northern part of the floodplain.

Human populations in the floodplain and seasonal migration

The floodplain contains a population of 225,000 people in an estimated 28,000 households. Given that the maximum floodplain landmass is 10,750 km^2 [18,24,25], the human population density of this is 20.6 people per km^2 during the dry months of July to November. It is estimated that another 200,000 people live on the plain margins. The livelihood of these individuals is also dependent on the floodplain, thus exerting more pressure on this region. The human population density decreases to less than five persons per km^2 during the rainy season when people migrate to the upland areas during periods of flooding (January to May). Livelihood and cultural traditions of the local inhabitants are tied to the flooding cycle [12]. Local inhabitants depend on fishing, farming, and a transhumance grazing system in which cattle are brought to the wetlands during the dry season. People and their livestock annually move out of the plains during the peak flooding period between January and April. This migration is marked by a traditional ceremony called Kuomboka that is headed by the local chief [12]. As the floodwater recedes, these people travel back to the plains together with their livestock, thereby increasing anthropogenic pressure on the floodplains [18].

Data collection

Records of livestock anthrax cases were obtained from annual reports of the Provincial Veterinary and Medical officers for the Western Province in Mongu (Zambia). Each district is subdivided into Veterinary Camps that are the smallest units under the Department of Veterinary and Livestock Services and cover an area with an average radius of 15 km^2. Rural Health Centers, the smallest administrative unit of the Ministry of Health, are subunits of district medical hospitals. Given that anthrax is a notifiable disease, it is mandatory that clinical officers report all cases diagnosed at Rural Health Centers to District Hospitals while Veterinary Assistants (VAs) in charge of Veterinary Camps report all animal cases to District Veterinary Officers. Once the district medical and veterinary officers are notified, public health experts perform a trace-back survey to establish the cause of the outbreak, determine the date when the first index case was observed, count the number of infected animals and people, determine the number of people and animals at risk, and gather information about other relevant details. From humans swabs from carbuncles and from animals swabs from oozing blood from orifices were collected for laboratory diagnosis.

"Outbreak" refers to a sudden occurrence of anthrax cases in localized areas such as a village or group of villages. In some cases an outbreak can extend over large areas, especially in situations where meat is transported to distant locations. Data from livestock and human cases are maintained in districts that submit monthly reports to the Provincial Medical and Veterinary Offices in Mongu. Data collected between 1999 and 2007 were analyzed in the present study. Outbreaks were confirmed by identification of *B. anthracis* bacteria as described elsewhere [6]. Data on human populations in Zambia, income per capita, and GDP annual growth rates were obtained from the Central

Statistical office, Zambia. Data analysis was performed with STATA/SE 10 software (Stata, USA). The likelihood ratio chi-square test was used to evaluate the association between occurrence of anthrax outbreaks and the wet season in the floodplain.

Results

Human anthrax cases

The distribution of human anthrax cases reported during 1999～2007 in the upper Zambezi floodplain is shown in Table 1. Overall, individuals in the upper Zambezi floodplain accounted for 84.9% (1,790/2,108) of the total anthrax cases recorded in humans between 1999 and 2007 (Tables 1 and 2). Cases of human anthrax in this region were highly correlated with livestock cases ($r = 0.94, p < 0.001$). Although the exact mode of transmission from cattle to each patient was not identified, observations from follow-up surveys conducted during the outbreaks indicated that people involved in skinning infected carcasses, handling meat, and processing skins and hides for making drums or stools were more susceptible to the disease than those who consumed cooked meat. Meat from animals that died on the floodplains was carried to upland areas to the owners for consumption or to be shared or sold. It is likely that inhalation of spores could play a minor role in infection through exposure to hides that were processed for use as sleeping mats or drums.

The cutaneous form of anthrax was most commonly reported with clinical signs developing within a fortnight after exposure to infected carcasses. The gastrointestinal form was the second most common although some patients were reported to have both forms. The cutaneous form was characterized by redness and edema of the skin leading to ulcerations that developed into curbancles. Laboratory diagnosis was carried out using swabs collected from the curbancles. The gastrointestinal form of anthrax typically developed within 7 days after exposure to infected carcasses. The disease presented as either an oropharyngeal or intestinal infection with major symptoms that included vomiting and diarrhea. Oral swabs were used for laboratory diagnosis for patients with oropharyngeal infections. The diagnosis of individuals with an intestinal infection was based on symptoms observed by experienced medical practitioners and confirming the presence of *B. anthracis* in the meat the patients ingested or carcasses they were

Table 1. Distribution of human clinical cases and anthrax-related deaths from 1999 to 2007

District	Year									Total
	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Kalabo	55 (2)	77 (3)	77 (6)	20	16 (1)	—	—	—	3	248 (12)
Lukulu	23 (2)	20 (2)	24 (4)	55 (3)	35 (3)	18 (2)	3 (1)	6	—	184 (17)
Mongu	129 (1)	96 (1)	79 (2)	100 (2)	99 (2)	108 (1)	21	7	1	640 (9)
Kaoma	45 (3)	76 (2)	6 (1)	3	48 (1)	39 (2)	2 (1)	11	3	233 (10)
Senanga	10	88 (1)	65 (3)	66 (2)	66 (1)	22	40	15	7	379 (7)
Sesheke	0	30 (25)	2 (1)	36 (1)	25	5	8 (1)	—	—	106 (28)
Total	262 (8)	387 (34)	253 (17)	280 (8)	289 (8)	192 (5)	74 (3)	39	14	1,790 (83)

The numbers of deaths are shown in parentheses.

Table 2. Humans population, income per capita, and the number of anthrax cases among humans and cattle in Zambia from 1999 to 2008

Year	Human population	Income per capita	GDP increase per year	Human anthrax cases	Cattle anthrax cases
1999	8,980,241	880	1.5	298	301
2000	9,582,418	880	4.0	432	255
2001	9,770,199	870	3.9	306	156
2002	9,959,037	890	4.2	316	259
2003	10,307,330	800	4.0	342	260
2004	10,462,440	900	4.6	241	148
2005	11,261,800	900	5.0	104	21
2006	11,447,450	1,000	6.0	48	40
2007	11,669,530	1,400	6.0	21	28

Table 3. Number of livestock cases diagnosed from 1999 to 2007 according to region

District	Year									Total
	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Lukulu	–	33	–	23	105	42	–	–	–	203
Kalabo	159	41	78	12	–	11	–	–	13	314
Mongu	50	72	8	132	44	40	10	–	3	359
Kaoma	38	13	31	23	66	11	–	–	–	182
Senanga	6	22	12	12	–	3	–	32	8	95
Sesheke	–	5	–	32	19	7	–	–	–	63
Total	253	186	129	234	234	114	10	32	24	1,216

exposed to. Although we did not determine the exact proportion of infected people, mortalities were mostly reported among patients with the gastrointestinal form. Most patients recovered after treatment with antibiotics. With this intervention, the overall case fatality rate was 4.63% (83/1,790).

Livestock anthrax cases

Animals in the upper Zambezi floodplain accounted for 83.4% of the total anthrax cases among livestock in Zambia between 1999 and 2007. In cattle, the disease was mainly characterized by sudden death with blood oozing from natural orifices. The number of livestock cases was high between 1998 and 2003, but declined in 2004 until the end of the study period (Table 3). Mongu was the most affected district (Table 3). Cases from the Kaoma district, which is not located in the floodplain, were cattle from Kaoma that grazed on the floodplain in the Lukulu and Mongu districts during the transhumance migration and were reported to the Kaoma Veterinary office by the owners. When animals from Kaoma died on the floodplain, the meat was taken for consumption back home to the owners of the animals, leading to cases of infected human reported by hospitals in Kaoma. Follow-up surveys carried out during outbreaks indicated that only a few cattle owners buried or burnt the anthrax-infected carcasses. The majority opened the carcasses and distributed the meat for consumption. In situations where the owners were not present when animals were dying, horns and skins were kept as evidence to show the owners that the animals died in their absence. In some cases, the hides were processed to make drums, mats, or stools, which posed the risk of preserving spores in these tissues for a prolonged period of time.

Seasonal variations

Seasonal distribution of anthrax cases is shown in Fig. 1. Our analysis demonstrated that occurrences of anthrax outbreaks varied according to season. Approximately five outbreaks ($\chi^2 = 4.75$, $p < 0.03$) appear to have occurred

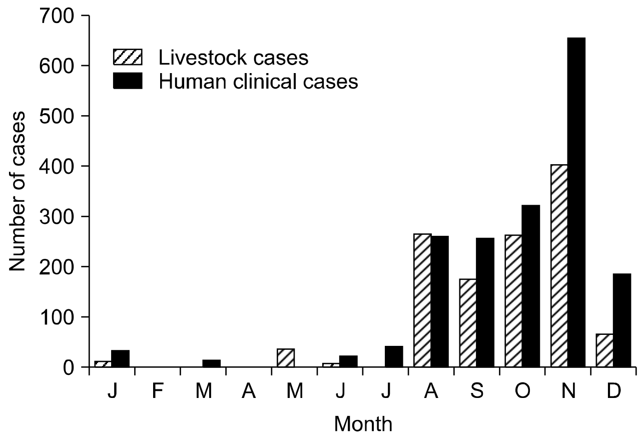

Fig. 1. Monthly distribution of livestock and human cases of anthrax from 1999 to 2007.

during the dry months when human dependency on the floodplain was higher compared to the months of flooding when people and their livestock moved out of the floodplain. Fig. 1 shows that number of anthrax cases was high between June and December, coinciding with the period when the human population density on the floodplain was high (20.6 person per km^2). This was in contrast to the periods of flooding between January and April when the human population density on the floodplain was low (less than five persons per km^2).

Discussion

Based on the significance influence of seasonal variation on occurrence of anthrax outbreaks observed in this study, it is likely that seasonality of the disease is more reflective of human activities on the floodplain rather than climatic effects. This is supported by the fact that the chances of anthrax outbreaks taking place during the dry months when humans were more dependent on the floodplain were about five times higher ($\chi^2 = 4.75$, $p < 0.03$) than the periods of flooding. Tuchili *et al.* [19] were able to isolate *B. anthracis* from soil samples collected from the floodplains but not the surrounding upland areas, indicating that anthrax spores were more enzootic in the floodplains than the uplands. Therefore, the transhumance grazing system involving the practice of bringing cattle to the floodplains during the dry season increases the chances of cattle being exposed to the spores.

Increases in the human population density to 20.6 persons per km^2 during the dry season (in contrast to less than five persons per km^2 during the rainy season) clearly indicate that greater human population density coincides with larger livestock populations during the dry season. This is due to the transhumance grazing system along with fishing and farming on the wetlands that increase human activities on the floodplain during the dry season [12,18]. This trend may be the reason why outbreaks of anthrax in livestock are highly correlated with infection in humans ($r = 0.94, p < 0.03$). The number of anthrax cases was high in the dry season, reaching a peak in November. At this time of the year, the floodplain is bare with little grass and the water levels are lowest. Animals, and especially cattle, graze close to the soil surface which increases the opportunity to ingest soil and anthrax spores. Furthermore, the animals crowd together at drinking points as water sources become scarce. The water can also be contaminated by nearby carcasses or vultures bathing after feeding on an anthrax-infected carcass. These factors have been associated with occurrence of anthrax outbreaks elsewhere [14,23].

Livestock outbreaks that started around June continued to occur until January when the local inhabitants moved out of the floodplains. Overall, our observations indicate that the ecology of the upper Zambezi floodplain influences the anthropogenic activities of the local inhabitants [12,18]. This in turn affects the epidemiology of the disease in the area. This is in line with observations made elsewhere [10] showing that seasonal recurrence of anthrax outbreaks may be a reflection of human activities rather than a direct effect of local climate on the disease. In the current study, we have provided a classical example of how human activities tied to seasonal variations can be linked to the recurrence of anthrax outbreaks in an area where anthrax spores are endemic.

Tuchili *et al.* [19] were able to isolate *B. anthracis* from dried meat produced in the Western Province, indicating that the processing and preservation methods used do not inactivate anthrax spores. This may be the cause of sporadic human outbreaks uncorrelated with livestock cases we observed outside the normal cyclical trend. Furthermore, Tuchili *et al.* [19] found anthrax spores in cattle hides that had been preserved and stored for a long time. Hides from animals dying of anthrax are often dried and later processed for making sleeping mats, chairs, stools, and drums which are sold to the general public, thereby increasing the risk of exposure to anthrax spores. Local traditions have also been one of the major factors that promote the persistence of anthrax in the area [22]. People working in urban areas who own cattle back home leave their animals under the supervision of caretakers. When an animal dies while owner is absent, the caretaker will keep the head, hide, or other body parts as evidence that the animal was not sold but died of disease. Anthrax spores can persist on the hides and other tissues taken and kept by caretakers.

The current passive surveillance system routinely requires VAs to visit cattle owners and identify animals that died of anthrax or other notifiable disease. This does not provide an adequate early warning system given the poor transportation and communication systems between the Veterinary Camps and district offices. It is probable that more animals will have died and the meat distributed before public health and district veterinary officers can travel to the site of the outbreaks. Hence, there is a strong likelihood that the number of animals infected during each outbreak will be underreported. Furthermore, not all human cases of anthrax are reported to rural health centers, especially in situations where the infected person easily recovers after resorting to treatment with natural herbs and other remedies. There is need to strengthen the public health surveillance system at the district level, and provide the VAs with more reliable transportation and communication systems. Trace back methods for outbreak follow-up tend to generate detailed information although there is lag-phase between reporting of the outbreak and the time taken for experts to travel to the site of the outbreak. This delay often leads to loss of important information.

Thus far, control measures have focused on teaching people not to eat anthrax-infected meat and encouraging them to correctly dispose of infected carcasses. Vaccination of cattle is mainly dependent on vaccines locally produced by the Central Veterinary Research Institute with an annual allocation of 100,000 doses for the Western Province that includes areas covering the upper Zambezi floodplain. However, this is inadequate for a cattle population of 300,000 that grazes on the floodplains during the dry season. Consequently, there is urgent need to increase the vaccination coverage that calls for increased vaccine production. Overall, declining numbers of anthrax cases observed during the last 3 years of the study period can be attributed to livestock vaccination carried out by the Department of Veterinary and Livestock Services and the positive response to public education. Although the impact of these public awareness and vaccination campaigns was not quantified in the present study, it is envisaged that government efforts are beginning to yield successful results.

Disease intervention should focus on breaking the cycle of anthrax transmission by vaccinating cattle at the end of the flooding season so that animals will have developed protective antibodies before they are moved to the floodplain. Currently, the only feasible method would be to perform annual vaccination of livestock along with improved public awareness campaigns designed to promote active participation by the general public in controlling this disease. Systematic burning or burying of anthrax-infected carcasses is virtually impossible to enforce in this region. Therefore, effective control will completely depend on ensuring that all cattle are vaccinated every year without exception and should continue until the disease has been eradicated. There is also an urgent need to carry out studies in order to identify ecological and environmental factors that favor the survival, persistence, and transmission of anthrax in the flood areas to develop appropriate measures that would mitigate the occurrence of anthrax outbreaks in the upper Zambezi floodplain.

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