Canadian Food Inspection Agency
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Risk Assessment on Bovine Brucellosis and Tuberculosis in Wood Buffalo National Park and Area

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Animal Health Risk Analysis
Analyse des risques zoosanitaires

Animal, Plant and Food Risk Analysis Network

Groupe d'analyse des risques zoosanitaires, phytosanitaires et alimentaires

Canada

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RISK ASSESSMENT SUMMARY

Risk assessments are science-based evaluations. They are not scientific research nor are they scientific manuscripts. The risk assessment forms a link between scientific data and decision makers and expresses risk in terms appropriate for decision makers. Information provided in this assessment is considered necessary, but not sufficient on its own, to provide the basis for regulatory decisions.

Summary of the Request:
Bison in and around Wood Buffalo National Park (WBNP) are infected with the organisms causing bovine brucellosis (*Brucella abortus*) and tuberculosis (*Mycobacterium bovis*). The continued presence of these diseases in bison in and around WBNP poses an undefined risk to the conventional livestock industry, commercial captive bison herds, and disease-free, free-ranging bison herds. This risk assessment was undertaken to quantify the risk to the three At Risk groups.

Statement on Components of Activity:

The risk assessment is conducted on the following components:
1) The risk to cattle located in the Fort Vermilion area.
2) The risk to commercial captive bison herds in Alberta and North East British Columbia.
3) The risk to disease-free, free-ranging bison herds: the Mackenzie Bison Sanctuary and the Hay Zama.
4) Six diseased herds which included herds in and around WBNP.

The risk assessment does not include GIS parameters in the movement modeling.

Summary of the Assessment:
The risk assessment assessed the probability of infection transmission to an individual animal, given that invasion and contact have occurred, and the economic consequences of infection transmission to an individual in a herd.

Statement on Overall Risk:

In 1998, there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with bovine brucellosis is less than 4.4×10^{-3}, if the geographic distribution and number of commercial bison farms and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 229 years if populations and distributions remain at 1998 levels. The monetary consequences of a brucellosis infection in commercial captive bison would total approximately $6.5 million per incursion or $28,000 for every year between outbreaks.

In 1998, there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with tuberculosis is less than 5.8×10^{-3}, if the geographic distribution and number of commercial bison farms and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 173 years if populations and distributions remains at 1998 levels. The monetary consequences of a tuberculosis infection in commercial captive bison would total approximately $8.2 million per incursion or $46,000 every year between outbreaks.

In 1998, there is a 95% probability that the estimated annual probability of at least one bovine becoming infected with brucellosis is less than 7.8×10^{-4}, if the geographic distribution and number of cattle and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 1,276 years if populations and distributions remain at 1998 levels. The monetary consequence of a brucellosis infection in cattle would total approximately $632,000 per incursion or $495 every year between outbreaks.

There is a 95% probability that the estimated annual probability of at least one bovine becoming infected with tuberculosis is less than $5.7x10^{-4}$, if the geographic distribution and numbers of cattle and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 1,764 years if populations and distributions remains at 1998 levels. The monetary consequence of a tuberculosis infection in cattle would total approximately $832,000 per incursion or $470 every year between outbreaks.

In 1998, there is a 95% probability that the estimated annual probability of at least one free-ranging bison becoming infected with bovine brucellosis is less than 0.02, if the geographic distribution and number of bison in free-ranging herds and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 50 years if populations and distributions remain at 1998 levels. The monetary consequences of a brucellosis infection in commercial captive bison would total approximately $5.4 million per incursion or $107,000 for every year between outbreaks.

In 1998, there is a 95% probability that the estimated annual probability of at least one free-ranging bison becoming infected with tuberculosis is less than 0.03, if the geographic distribution and number of bison in free-ranging herds and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 33 years if populations and distributions remain at 1998 levels. The monetary consequences of a tuberculosis infection in commercial captive bison would total approximately $5.4 million per incursion or $162,000 every year between outbreaks.

TRACKING FORM

Process Initiation and Dates:
March 1997: request received from AHD

Risk Assessment Versions and Dates:

Preliminary report presented at the Canadian Animal Health Consultative Committee Meeting, December 8, 1997.
Copy of presentation submitted to Dr. Claude Lavigne, December 9, 1997.

Data Systems Searched & Key Words Used:

CABI: brucell*, tubercul*, bison
Parks Canada ProCite database on Wood Buffalo National Park
Montana State University, Center for Bison Studies - Bibliography and Abstracts on Bison Diseases Website (http://www.monyana.edu)
Greater Yellowstone Interagency Brucellosis Committee Website (http://www.nps.gov/gyibc/index.htm)

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HISTORY OF RISK ASSESSMENT REQUEST

History, background and rationale of the request:

March 1996 - Animal Health Division requested a risk assessment based on a submission from the Canadian Bison Association. The Canadian Bison Association had requested the Minister of Agriculture and Agri-food Canada to undertake a risk assessment on bovine tuberculosis and brucellosis in bison in and around Wood Buffalo National Park and the potential for spread from this area. The motivation for this request was the recent movement of bison from a captive bison herd near Hook Lake, NWT into Alberta. The bison herd in question had been tested under the Captive Ungulate Program and qualified for a movement permit.

October 1996 - Presentations by the Province of Alberta and the Canadian Bison Association at the Canadian Animal Health Consultative Committee meetings emphasized the concern over the presence of the infected bison in and around Wood Buffalo National Park. The Canadian Bison Association requested an analysis of the risk of infection of captive and free-ranging bison herds in the affected region and the potential impacts of the risk on national and international trade. Furthermore, the analysis needed to consider the risk under current conditions and under likely future scenarios as the number of ranches and the size of disease-free captive and wild herds continue to increase in the region. The Canadian Bison Association considered the captive and free-ranging disease-free bison in the region to have a higher risk of exposure than cattle and that the bison industry is more likely to suffer with respect to domestic and international markets.

February 1997 - Animal Health Division changed the priority of the risk assessment request from low to high and requested a revised assessment of the risks posed by Wood Buffalo National Park to the domestic cattle and captive ungulate populations arising from the proliferation of domestic bison ranching outside of the Park. A linkage was noted between this assessment and a review of the programs related to brucellosis and tuberculosis surveillance and the Captive Ungulate Program as mentioned in the Auditor General's report.

March 1997 - Concern expressed by the Canadian Cattlemen's Association that the US National Cattlemen's Association may use the continuing existence of bovine tuberculosis and brucellosis in the Wood Buffalo National Park and area as a trade barrier.

HAZARD IDENTIFICATION

Hazard	OIE List
VIRUSES	
RICKETTSIAE	
BACTERIA	
Brucella abortus	B
Mycobacteria bovis	B
FUNGI	
PROTOZOA	
PARASITES	
OTHER	

REFERENCES

Tessaro S.V., Forbes L.B. and Turcotte C. 1990. A survey of brucellosis and tuberculosis in bison in and around Wood Buffalo National Park, Canada. Can. Vet. J. 31:174-180.

Joly D.O., Leighton F.A., Messier F. 1997. Tuberculosis and Brucellosis Infection of Bison in Wood Buffalo National Park, Canada: Preliminary Results. Unpublished document from the University of Saskatchewan and Western College of Veterinary Medicine.

SCOPE OF THE RISK ASSESSMENT

Hazards: 1. *Brucella abortus*
2. *Mycobacterium bovis*

Risk Source: Bison in and around Wood Buffalo National Park

At Risk groups: 1. Cattle
2. Commercial captive bison
3. Disease-free, free-ranging bison. In this risk assessment two herds located closest to infected bison were selected: the Mackenzie Bison Sanctuary herd and the Hay-Zama herd.

Risk assessed: The risk of infection with *Mycobacterium bovis* or *Brucella abortus* from bison in WBNP and surrounding area during a 12 month period, for each of three identified " At Risk " groups: cattle, commercial captive bison and disease-free, free-ranging bison.

RISK ASSESSMENT APPROACH

1.	Release Assessment:	Estimate the probability of invasion, and given that invasion occurs estimate the probability of contact.
2.	Exposure Assessment:	Estimate the probability of infection transmission, given that contact occurs.
3.	Consequence Assessment:	Estimate the consequences of infection transmission, given invasion and contact.
4.	Risk Estimation:	Estimate the risk given invasion, contact, infection transmission and the consequences of infection transmission.

Geographic Information Systems (GIS):
GIS modelling has been investigated, but not included in this risk assessment. Inclusion of GIS variables in the model may increase the overall risk estimate. The increase in risk would likely be associated with the logging activity occurring around the south west corner of the WBNP. The increase in logging roads and clearcuts make it easier for bison to travel out of the park and therefore lead to the predicted increase in risk.

In our risk assessment, bison have been modelled to move equally in all directions. Movement however, in any given direction, will be affected by many variables including vegetation, topography, hydrography, barriers (natural and man made) and pathways or movement corridors (cut lines and roads). Different approaches for including GIS variables have been discussed with the GIS and remote sensing specialist at Research Branch (CANSIS) and with a GIS Analyst at Innovative GIS Solutions located in Fort Collins, USA.

Biophysical characteristics of the landscape and other factors are presumably already reflected in current data, but lumped into the general variability. A few more comments regarding "micro-modeling" versus a "macro" approach:
a. More and lower-level data needs; often no hard data exist,
b. Increased model complexity usually requires more assumptions and conditions, making verification/validation difficult,
c. In particular, it is a general phenomenon that introducing more parameters into the model often reduces variability at the expense of bias due to model mis-specification;
d. Lacking hard data at lower levels often leads to the use of soft data and subjective information to derive parameters, resulting in an increase in uncertainty/variability level in prediction.

Nonetheless, the above concerns do not prevent us from recognizing that biophysical environment modeling is an interesting and potentially promising direction, particularly with the availability of many satellite and other remote sensing data. We had indeed actively explored this possibility. A lack of time and resources was the major reason for not pursuing it further.

RELEASE ASSESSMENT:
PROBABILITY OF INVASION

DESCRIPTION OF THE INVASION PROBABILITY MODEL

Introduction

The major (in fact the motivating) concern of this risk analysis is the rare but possible scenario in which infected bison meet disease-free, free-ranging bison, cattle or commercial captive bison that are susceptible to tuberculosis or brucellosis. This can only happen when (either infected or healthy) free-ranging bison roam beyond their regular home range. Therefore, a key element of the risk assessment is not the normal range, but rather the extreme movement of bison. In other words, we have to construct probability models for the maximum range of a particular herd of free-ranging bison.

To make the models meaningful as well as practical, we also have to define a time unit (time horizon) for risk assessment in general and the "maximum range" in particular. From both standard quantitative risk analysis practice and the available bison movement data, year would be a logical choice for this unit.

In addition to the focus on extreme movement, another challenge in this assessment is that the probability distribution we need to construct is not on individual animals, but that of a collective group (herd or population). We may safely say that these two features, namely extreme range and collective behaviour, are what make this study unique and challenging, because there is little in the existing literature to draw from.

A third complication or challenge, is to address the issue of bi-directional movement. This is also a very difficult and likely unprecedented issue for this type of risk assessment.

Thanks to the Wood Buffalo National Park Study (Wood Buffalo National Park 1995), we have some solid radio telemetry data on individual bison movement. However, they are far from adequate or sufficient for developing a sophisticated risk model to accommodate most known or perceived factors. Nevertheless, we are able to build models from this database.

Description of Telemetry Data Set

The Wood Buffalo National Park Study collected more than one thousand entries of relocation data on 111 radio-collared, free-ranging bison collected over a three (3) year period spanning 1990 to 1993. In total, there are 2,400 observations in the database of which 1,000 are from mature males. Bison were radio-collared in five general regions of the park which included: Peace Athabasca Delta (Sweetgrass), Pine Lake, Needle Lake, Garden River and Little buffalo River. The collared males included lone males and males collared near the borders of the park.

The data volume may appear sufficient when utilized for modelling the maximum range based on our chosen time unit, namely year, however this database is barely enough for some preliminary models. The major reason is the short coverage time for many radio-collared bison.

In order to maximize the utility of the database, we have adopted bison-year as an analysis unit, which is customized to each bison. More specifically, for each bison, the year starts on the first relocation entry date and lasts 365 days, after that the second year starts, etc.. To further increase the number of sample units, any remaining time period with at least 300 days between the first and last relocation entries is included as a valid bison-year. In total, we have 86 such bison-years for modelling.

Breakdown by Gender and Age:
The subset of telemetry data used in the risk assessment included 86 sets of data covering a one year span. Of the 86 annual sets 33 (38%) were from mature males (27 bulls 7-8 years, 6 bulls greater than 8 years) and 53 (62%) were females. When the data is stratified by gender, the maximum distance travelled by males was 125 kms with a mean and median of 46 and 52 kms respectively. For females, the maximum distance travelled was 106 kms with a mean and median of 44 and 49 kms respectively.

Modelling Individual Extreme Movement
For each bison-year, a centre-of-activity is calculated by either mean or median UTM coordinates. Then, the maximum annual deviation r is calculated as the largest Euclidean distance between the relocation point and the centre-of-activity. The direction (phase) associated with that maximum deviation is also calculated.

The probability distribution of the annual maximum deviation is of primary interest for model development. The distribution between mean and median centre-of-activity appears quite similar. We decided to use median because it is more robust and is much less influenced by extreme values (which are exactly what we try to model), therefore making the resulting annual maximum deviation more reliable.

The directional data are certainly also of interest. But due to the small sample size, lack of meaningful terrain data, and some complex methodology issues, they have not been utilized. We take a conservative approach by assuming that the maximum deviation can happen in all directions.

We fit a parametric model to the sample data so that we can make inferences in order to extrapolate beyond the observed data range. After extensive exploration, a log-normal distribution (Appendix A) appears the best model. Therefore, we have estimated the parameters of a probability distribution, denoted thereafter as a probability density function (also known as a probability curve) f(r), based on the observed telemetry data for the annual maximum range of an individual bison. This probability density function forms the basis of our risk estimation.

The most serious constraint is the amount and type of available data. This limits the inclusion of known risk factors into the model. There are roughly two categories of risk factors, those involving the bison herd and those involving the environment.

The first category is essentially animal characteristics, age and gender in particular, which are in fact collected in our telemetry database. Due to the collective nature of the problem and the fact that a herd is always a heterogeneous group, it would seem most appropriate to model at the macro (i.e. herd) level. More specifically, the aforementioned probability density f(r) should be a function of the age and gender profile of a herd. This can be modelled by analysing the relationship between maximum range and the individual characteristics of interest and developing suitable regression equations. We have indeed tried this approach. But with the given sample size, we failed to obtain any significant associations. One possibility not requiring more data is to perhaps work on a shorter time unit, say season, to develop the associations.

Dr. Cormack Gates has kindly provided us with a list of environmental factors: terrain features (both natural and manmade), food supply, etc. However, major difficulties at this point to incorporate these factors into our model are (a) how to quantify these factors and (b) a lack of necessary field data. Nonetheless, we think a comprehensive risk model should include these important factors.

Future work could incorporate the environmental factors with general directional preference and by developing a factorial model like

$$h(r,\alpha) = f(r,\theta_1)\, g(\alpha, \theta_2),$$

where α represents direction, θ_1 and θ_2 are parameter (risk factor) vectors.

Modelling Collective Extreme Movement

While the probability distribution of an individual is an important starting point, one realizes that the risk is embodied by an entire herd or population of infected bison and it may take any single infected animal to spread the disease to other herds or animal populations. In other words, what really matters is the collective extreme movement of an entire herd, not that of a single individual.

Two problems associated with this are a collection of centres-of-activity and the lack of independence between the movement of bison from the same herd.

The first difficulty can be addressed by taking a conservative approach of measuring the maximum deviation starting at the boundary of a common core area in which centres-of-activities are located.

The second difficulty is much more complex and challenging. The difficulty is two-fold. First, classical results on collective extreme value distributions invariably assume individual observations are identically and independently distributed (iid). In our case one can hardly assume any independence regarding the movement of bison within the same herd. Though in the past two decades there has been some progress in the probability theory of extreme order statistics for the so-called non-iid case, often relying on the notion of interchangeable events, the mathematics is almost always complex and abstract, difficult to apply. Secondly, we do not have any direct data to estimate the intra-herd correlation, an essential element in modelling dependence.

After an extensive review of recent relevant developments in probability theory, we decided to adopt a relatively simple additive model of interchangeable random variables to reflect the intra-herd dependence. For a single bison i, its annual maximum deviation is modelled as

$$r_i = v_i + z,$$

where v_i follows a common yet independent log-normal distribution, and z follows a normal $(0, \delta_z)$ distribution. It is not difficult to see the above model introduce a correlation between any two bison of the same herd of

$$\rho = \frac{\delta^2}{\delta^2_v + \delta^2_z}$$

Therefore, in order to decompose the total variance of r_i into correct proportions reflecting the true intra-herd correlation, the estimation of ρ is crucial. But we do not possess direct data, namely following and recording the movement of a particular yet representative pair for many years using the same time schedule, for this estimation.

After a careful examination of the available telemetry data and much mathematical derivation work, we have finally solved this estimation problem using the observed herd size record, namely the number of bison seen together with the radio-collared individual every time relocation is made.

If individual bison in a herd of n all have the same centre-of-activity, the herd collective maximum deviation is then

$$r_{max} = max\ v_i + z$$

Because v_i's are independent of each other, classical distribution result of maximum order statistics can be applied, plus a convolution with the distribution of z, and we obtain the final probability distribution of the herd extreme range.

Naturally individuals within the same herd will have close but dispersed centres-of-activity and the above result cannot apply directly. But once we define a core area for the centres-of-activity for the entire herd, and measure the above herd maximum range starting at the boundary of this core area, then we obtain a conservative probability distribution for the risk of concern.

Presentation of Results

For the current preliminary report, we will assume the same weight for all directional movement of bison. Following the above discussions, for each herd of interest, whether infected or healthy, probability contours can be drawn for various probabilities showing the maximum range of the annual herd movement. These contours can be used, among others, for:

- Estimating the probability of individual(s) from a certain herd moving into a particular area of concern;
- Comparing and evaluating the relative risks posed by different infected herds;
- Modelling bi-directional movement scenarios.

INPUTS FOR THE INVASION PROBABILITY MODEL

Model inputs include sizes of infected herds in and around WBNP, distances between infected herds and the At Risk groups and contact angle between infected herds and At Risk groups.

WBNP Herds

The risk assessment focused on six diseased herds in and around WBNP (Map 1). The Geographic Information Software (GIS) software program ARC/INFO (Environmental Systems Research Institute, Toronto, 1994) was used to map the home ranges of the diseased and disease-free, free-ranging herds. A list of the six diseased herds included in the risk assessment and their sizes are presented in the following table:

	[illegible]	[illegible]	[illegible]	[illegible]
1	Inside Park	Central WBNP (Pine Lake)	852[1]	
2	Inside Park	Garden River (Includes Wentzel Lake)	610[1]	Because of the proximity and suspected interchange, the Garden River and Wentzel Lake herds were considered together.
3	Inside Park	Needle Lake (Nyarling River)	229[1]	
4	Inside Park	Peace Athabasca Delta (Sweetgrass)	382[1]	
5	Outside Park	Wabaska	59[2]	
6	Outside Park	Slave River Lowlands	253[1]	Because of the proximity and suspected interchange, the Little Buffalo River and the Hook Lake herds were combined into one herd and called the Slave River Lowlands

[1] Source: Doug Bergeson, Park Warden, Wood Buffalo National Park
[2] Source: Teleconference with Dr. Dale Armstrong Oct.'97

Individual herd sizes vary from year to year although the total for the six herds has not varied greatly in the last several years. This shift in herds sizes represents a source of uncertainty which was difficult to model. We have chosen to represent this input as a point estimate because of the lack of information on how shifts in herd sizes occur from year to year.

Commercial Captive Bison

E_1 A database, created in 1993, which listed the UTM co-ordinates of 130 commercial bison farms in Alberta and North East BC (Gates C. 1997) was used to get an estimate of distance and contact angle. Although generated in 1993, the database was found to accurately reflect the current location of bison farms (Quist 1998, Copeland *et al.* 1998). The Geographic Information Software (GIS) software program ARC/INFO (ESRI, 1994) was used to map the location of the 130 bison farms in the database.

E_2 Distance: ARC/INFO was used to measure the distances between the 130 bison farms and each of the six diseased herds. In the final model, a truncated normal distribution was used for all except the Wabasca Herd to represent the distance between a diseased herd and bison farms. A gamma distribution was used for the Wabasca Herd. The software program BestFit (Palisade Corporation, Neufield, New York) was used to select distributions which best represented the data.

E_3 Contact Angle: A geometric formula was used to calculate the contact angle for individual farms (Angle = arccosine ($b^2 + c^2 - a^2/2bc$, where a, b and c are the sides of a triangle). The distances between the bison farms and the diseased herds (see above) were used for two sides of the triangle and the diameter of the area of a bison farm was used for the third side. A Triangular distribution was used to represent the area of a farm with the most likely value being 450 acres, minimum 160 acres and maximum 2,000 acres (Copeland *.et. al.* 1998). This contact angle for an individual farm is multiplied by an estimate of the number of bison farms in Alberta and N.E. British Columbia. A point estimate of 500 was used based on 1996 Census data and projections of industry growth a 15% annual increase in the number of farms (Hussey 1997). Data for Alberta and N.E. British Columbia (we assumed that 80% of total bison population of BC was located in the NE part of the province) were used in this risk assessment.

Cattle

E_1 Data on cattle in the census Municipal District (MD) 23, located in the area adjacent the western and southern boundaries of WBNP, were used to assess the risk to cattle. A detailed census district map (Alberta Environmental Protection Provincial Base Map, 1995) was used to establish the more precise location of cattle in MD 23. Cattle in MD 23 were determined to be confined to the area in and around the Fort Vermilion area extending as far east as Beaver Ranch and North Tall Cree Indian Reserve (Quist 1998)

E_2 Distance: For each diseased herd, five distances were measured between the home range of the diseased herd and Fort Vermilion where the cattle are located. ARC/INFO was used to measure the distances. The contact angle was divided into five subsections. The subsections were selected in such a way as to ensure that they reasonably represented the spectrum of distance within the contact angle for each disease herd. In the final model, the distances are represented by discrete uniform distributions using the five distance estimates described above.

E_3 Contact Angle: A geometric formula was used to calculate the contact angle for individual farms (Angle = Arccosine ($b^2 + c^2 - a^2/2bc$, where a, b and c are the sides of a triangle). ARC/INFO was used to estimate the distances of the sides of the triangle used in the geometric formula.

Disease-Free, Free-Ranging Bison

E_1 A 1998 survey by the NWT Resource, Wildlife and Economic Development, estimates the size of the Mackenzie Bison Sanctuary herd to be 1,905 bison.

E_2 A 1998 survey by the Alberta Environmental Protection, Natural Resources Service, estimates the size of the Hay Zama herd to be 120 bison.

INVASION PROBABILITY MODELS

Unidirectional model for Commercial Bison Farms and Cattle

For each diseased herd, the Pr *(Invasion)* is calculated using the model :

$$\text{Pr } (\textit{Invasion}) = (1-(\text{NORMSDIST}((\text{Ln}(d)-3.8413)/0.3827))^{h}) \times (a/360)$$

where,

d = distance between the diseased herd and the *At Risk* group
h = size of the diseased herd
a = contact angle between the diseased herd and the at risk group

The total Pr (*Invasion*) (*I*) is:

$$= 1 - ((1-P_1) \times (1-P_2) \times (1-P_3) \times (1-P_4) \times (1-P_5) \times (1-P_6))$$

where,

P_i = Pr (*Invasion*) for each of the i = 1-6 diseased herds

Bi-directional Model for Disease-Free, Free-Ranging Bison

The invasion probability for disease-free, free-ranging bison must consider movement by both the disease-free and diseased, free-ranging bison. Telemetry data for the MBS herd was supplied to us by John Nishi, Bison Ecologist with Resource, Wildlife and Economic Development of the Government of the North West Territories. Analysis of the MBS data revealed a smaller annual movement range than the WBNP data. This may be due to the fact that the MBS data had a much lower relocation frequency. To ensure that we did not underestimate the risk of contact, we opted to use the telemetry data from WBNP to model the movement of bison from the Mackenzie Bison Sanctuary and the Hay Zama herds.

The invasion probability for the disease-free, free-ranging bison is more appropriately termed a probability of spatial meeting with the diseased bison. The model overestimates the probability of spatial meeting since the temporal movement of the diseased and disease-free bison has not been considered. The probability of spatial meeting between diseased and disease-free, free-ranging bison was estimated by computing the probability that bison from a diseased herd and bison from a free-ranging herd known to have diseased bison would not meet. The latter is the probability P_{AB} that two herds (Herd A, a diseased herd and Herd B, a disease-free herd) have a disjoint maximum annual range. This probability can be written as follows:

$$P_{AB} = \int_0^d P_B(outside\ x+dx) \cdot P_A(x+dx)$$

Figure 1 illustrates and defines the terms employed in the expressions above and below.
Dividing the entire distance d into m+1 segments in which

$$x_0 < x_1 < x_2 < \ldots x_m < x_{m+1} = d.$$

The equation for P_{AB} can then be approximated by:

$$P_{AB} = \sum_{i=0}^{m} (P_B(outside\ x_{i+1}) \cdot P_A(x_i,\ x_{i+1}))$$

$$where\ x_{i+1} = r_A + \frac{i+1}{m} \cdot d, \quad x_i = r_A + \frac{i}{m} \cdot d.$$

P_A can be approximated by: $$P_A \approx h\ (x_{i+1},\ n_A,\ 2\pi) - h(x_i,\ n_A,\ 2\pi)$$

$$\approx (Normal\ Z\ Dist.(\frac{LN(x_{i+1})-3.8413}{0.3827}))^{n_A} \cdot \frac{2\pi}{2\pi} - (Normal\ Z\ Dist.(\frac{LN(x_i)-3.8413}{0.3827}))^{n_A} \cdot \frac{2\pi}{2\pi}$$

P_B (outside x_{i+1}) can be decomposed into $P_B^{(1)}$ (outside x_{i+1} and α_{max}) + $P_B^{(2)}$ (outside x_{i+1}, inside α_{max}) where α_{max} defines the tangent from herd B centre to the circle x_{i+1}.

$$P_B^{(1)} = \frac{2\pi - 2\alpha_{max}}{2\pi} \ where \ \alpha_{max} = \arcsin \frac{x_{i+1}}{r_A + r_B + d}$$

$$P_B^{(2)} = \int_{-\alpha_{max}}^{\alpha_{max}} P_B\ (within\ y,\ d\alpha) = 2\int_0^{\alpha_{max}} P_B\ (within\ y,\ d\alpha)$$

Dividing the angle α_{max} into k equal segments of size α_{max}/k, $P_B^{(2)}$ can be approximated by:

$$P_B^{(2)} \approx 2\sum_{j=1}^{k} (Normal\ Z\ Dist.(\frac{LN(y_j)-3.8413}{0.3827}))^{n_B} \cdot \frac{\alpha_{max}}{k}$$

$$y_j = (r_A + r_B + d)\cdot\cos(\frac{j}{k}\ \alpha_{max}) - \sqrt{[(r_A + r_B + d)\cdot\cos(\frac{j}{k}\ \alpha_{max})]^2 - [(r_a + r_b + d)^2 - (x_{i+1})^2]}$$

$P_B^{(2)}$ can be simplified with an approximation as follows:

$$(Normal\ Z\ Dist.(\frac{LN(\lambda_1)-3.8413}{0.3827}))^{n_B} \cdot \frac{\alpha_{max}}{2\pi} + (Normal\ Z\ Dist.(\frac{LN(\lambda_2)-3.8413}{0.3827}))^{n_B} \cdot \frac{\alpha_{max}}{2\pi}$$

The probability of spatial meeting can then be estimated as follows using the simplified approach:

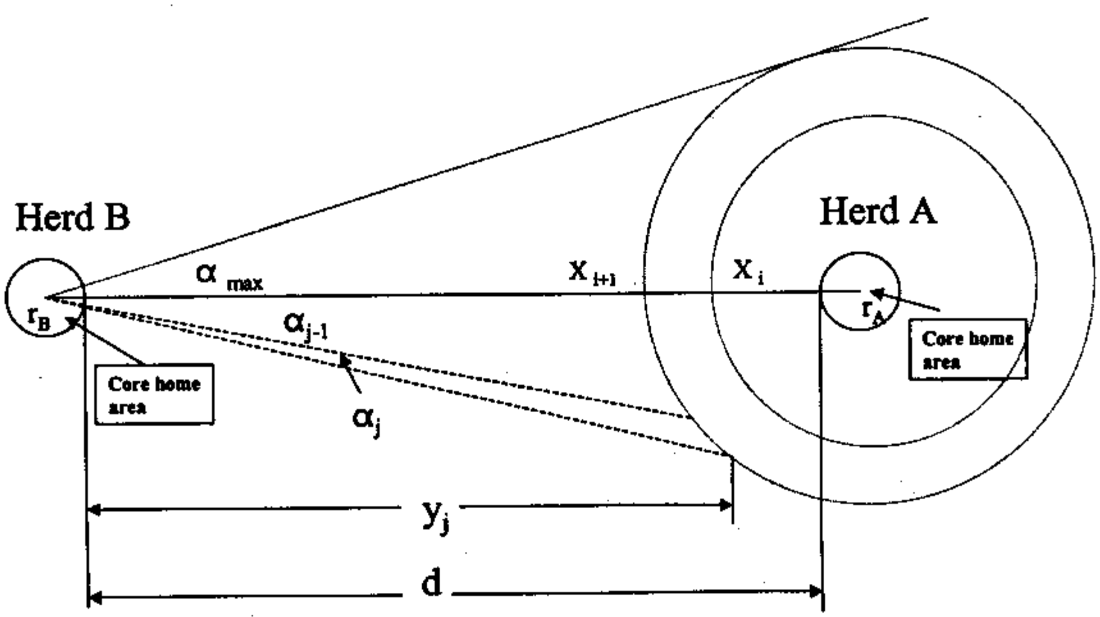
$$P_{AB} = \sum_{i=0}^{m} (P_A \times (P_B^{(1)} + P_B^{(2)}))$$

Therefore the probability of spatial meeting between bison in the 6 diseased herds and the Hay-Zama and Mackenzie Bison Sanctuary herds can be approximated by:

$$P_{Spatial\ Meeting} = 1 - \prod_{i=1}^{6} \prod_{j=1}^{2} (\sum_{i=0}^{m} (P_A \times (P_B^{(1)} + P_B^{(2)})))$$

where, I = 1 to 6 diseased bison herds and j = 1 to 2 free-ranging herds.

Figure 1. Bidirectional model for assessing the spatial contact probability between diseased bison and free-ranging bison



INVASION PROBABILITIES

Commercial Captive Bison
In 1998, there is a 95% probability that the estimated annual probability of at least one bison from WBNP and area invading the area occupied by commercial bison farms is less than 3.35×10^{-2} if the geographic distribution and number of commercial bison farms and diseased herds remains constant. In other words, one can state with 95% confidence that on average invasion would occur no more frequently than once every 29.9 years if populations and distributions remain at 1998 levels.

Cattle
In 1998, there is a 95% probability that the estimated annual probability of at least one bison from WBNP and area invading the Fort Vermilion/La Crete area is less than 0.37 if the geographic distribution and number of cattle and diseased herds remains constant. In other words, one can state with 95% confidence that on average invasion would occur no more frequently than once every 2.7 years if populations and distributions remain at 1998 levels.

Disease-Free, Free-Ranging Bison
In 1998, the estimated mean annual probability of at least one bison from WBNP and area meeting free-ranging bison is 0.10 if the geographic distribution and number of bison remain constant. In other words, on average a disease free bison from either the MBS herd or the Hay Zama herd is once every 10 years. Note that the 95% upper limit would be higher than once in 10 years.

RELEASE ASSESSMENT:
PROBABILITY OF CONTACT | INVASION

To become infected, a susceptible animal must come in contact with an infectious animal or, in the case of brucellosis, discharges that contain a sufficient dose of viable *Brucella* organisms. Separation in space and time reduces the potential for transmission. Determining if At risk and diseased animals are located together spatially and temporally may include a subjective evaluation of animal behaviour which was not undertaken in this risk assessment. Other meaningful evidence for assessing the probability of contact which are available include: the density of animals in the At risk groups, the maximum contact area and the presence of a fence.

Commercial Captive Bison:

E_1 Density: The average density of bison on farms is estimated to be 63 head /sq km. This estimate was calculated using 1996 Census data and projections of industry growth of 25% annual increase in bison numbers and 15% annual increase in the number of farms (Hussey 1997). Data for Alberta and N.E. British Columbia (we assumed that 80% of total bison population of BC was located in the NE part of the province) were used in this risk assessment. Area of farms was based on a most likely size of 450 acres (Copeland *et al.* 1998).

E_2 Contact Area: Contact area is defined as the maximum area in which an infected bison and a disease free bison would have a probability of coming in contact with each other, if they are both located in that area at the same time. At a density of 63 head per sq km we consider that if a diseased bison invades the area occupied by commercial captive bison, contact will occur.

E_3 Fencing: There is widespread agreement that the presence of a fence has little effect on preventing the movement of bison if bison are determined to go through a fence (Pauls 1998). Therefore, in this risk assessment, we consider that the presence of a fence will have no effect on reducing the probability of contact with commercial captive bison.

Therefore, for commercial captive bison:

$$\Pr(\mathit{Contact} \mid \mathit{Invasion}) = 1$$

Cattle:

E_1 Density: The density of cattle in the Fort Vermilion area is one head per 3.7 sq km (0.016 head/sq km). This estimate was calculated using 1996 Census data for total number of cattle and ARC/INFO to measure the total area where cattle are located west and south of the WBNP.

E_2 Contact Area: Contact area is defined as the maximum area in which an infected bison and a bovine would have a probability of coming in contact with each other, if they are both located in that area at the same time. The contact area is consider to be larger for brucellosis than for tuberculosis because of the persistence of *B. abortus* organism in the environment. Based on pasture sizes described in experimental work (Davis *et al.* 1990) for brucellosis, we assume the maximum contact area to be 0.1 sq km (10 hectares). For tuberculosis we consider the maximum contact area to be 0.06 sq km (6 hectares).

E_3 Fencing: A fence is considered to be effective for keeping cattle in pastures and therefore out of areas surrounding the pastures which may be invaded by bison; however, the fence is assumed to have little effect on keeping bison out if bison are determined to go through the fence and into areas occupied by cattle. We also assume that the species difference will decrease the likelihood that bison will invade areas occupied by cattle. Therefore, in this risk assessment, for the risk to cattle, we conclude that the presence of a fence will most likely reduce the probability of contact by 50% with a minimum probability of 40% and maximum of 60%. This input will be represented in the model by a Pert distribution (*minimum, most likely, maximum*).

Therefore, for cattle:

$$Pr\,(Contact \mid Invasion) = [\text{Contact area / area per head of cattle}] \times [\text{Probability of contact} \mid \text{A Fence}]$$

For brucellosis,

$$Pr\,(Contact \mid Invasion) = (0.1 / 3.7) \times \text{RiskPert}(0.4,0.5,0.6)$$

For tuberculosis,

$$Pr\,(Contact \mid Invasion) = (.06 / 3.7) \times \text{RiskPert}(0.4,0.5,0.6)$$

Disease-Free, Free-Ranging Bison

The "Invasion Probability" model for disease-free, free-ranging bison concurrently considered the probability of contact. Therefore, a separate assessment for the probability of contact was not necessary.

For disease-free, free-ranging bison we consider that :

$$Pr\,(Contact \mid Invasion) = 1$$

EXPOSURE ASSESSMENT:
PROBABILITY OF TRANSMISSION
HAZARD: *Brucella abortus*

The same model for the probability of transmission of *B. abortus* given that invasion and contact occurs, is used for cattle and bison because of the similar nature of the disease in cattle and bison.

E_1 The prevalence of brucellosis in WBNP bison in 1997 was estimated to be 29% (37/127) by complement fixation and the buffered plate antigen testing (BPAT) (Joly *et al*, 1997). Using sero prevalence may overestimate the number of infectious animals and therefore may increase in the risk estimate. This input will be represented in the model by a Beta distribution (*alpha1, alpha2*).

E_2 The BPAT has a reported sensitivity in cattle of 75.4%-97.9% and specificity of 98.6-100% (Neilsen *et al.* 1996, Stemshorn *et al.* 1985, Uzal *et al.* 1995). The complement fixation test has a sensitivity of 79-97.6% and specificity of 99.9-100% (Neilsen *et al.* 1996, Stemshorn *et al.* 1985). The sensitivity of brucella testing in bison has been estimated to be 92% when compared to culture (Dobson *et al.* 1996).

E_3 The usual mode of transmission is oral contact with aborted fetuses and placentas (Dobson *et al.* 1996, McCorquodale and DiGiacomo 1985). In temperate climates, infectivity may persist for 100 days in winter and 30 days in the summer. (Radostits *et al.* 1994). This input will be represented in the model by a Uniform distribution *(minimum, maximum)*.

E_4 The calving season for bison in WBNP is April 1 to June 15 (Wood Buffalo National Park, 1995).

E_5 The clinical disease is similar to that seen in cattle (McLeod and Van Tassell 1996). Abortions occur in the last trimester, around five to eight months of pregnancy.

E_6 Evidence in E_4 and E_5 will be used to estimate the portion of the year where exposure to *B. abortus* organism can occur. This input will be represented in the model by a Triangular distribution (*minimum, most likely, maximum*).

E_7 Few reports are available on natural infections in bulls (Plant *et al.* 1976). Bulls are capable of transmitting brucellosis, however, this is considered to be a rare event. For *Brucella* organisms to be shed in semen, it must be localized in the reproductive ducts.

E_8 Bulls do not transmit infection from infected to non-infected cows mechanically (Radostits *et al.* 1994).

E_9 50% of susceptible cattle in contact with bison experimentally infected with *B. abortus* became infected. Infection was confirmed by serology (Davis *et al*, 1990). Transmission from bison to cattle (7 of 12 susceptibilities became infected) did not differ statistically from cattle to cattle transmission (6 of 12 susceptible) under identical conditions. This input will be represented in the model by a Beta distribution (*alpha1, alpha2*).

The probability of transmission of brucellosis ($T_{Brucella}$) to at least one *At Risk* animal, given invasion and contact can be estimated by:

$$\Pr(T_{Brucella} \mid Invasion \cap Contact) = p \times e \times t$$

where,

p = true prevalence of brucellosis in bison from WBNP (see below)
e = portion of the year where exposure to *Brucella* can occur
t = rate of disease transmission | contact animals are infected (Beta(8,6))

and where p is estimated by:

$$= AP - (1\text{-}Sp) / 1\text{-}((1\text{-}Sp) + (1\text{-}Se))$$

where,

AP = apparent prevalence (Beta (38,91))
Se = sensitivity of the test (point estimate, 0.92)
Sp = specificity of the test (point estimate, 1)

and where the portion of the year where exposure to *Brucella* can occur (e) is estimated by:

$$e = (a + b)/365$$

where,

a = no. days where exposure to brucella can occur (abortion + breeding seasons) (Triangular(90,150,365)).
b = no. days *B. abortus* can persist in the environment (Uniform(0,100))
In the model, if e is greater than 1, then a probability of 1 is used.

EXPOSURE ASSESSMENT:
PROBABILITY OF TRANSMISSION
HAZARD: *Mycobacterium bovis*

The same model for the probability of transmission of *M. bovis* given that invasion and contact occurs is used for cattle and bison because of the similar nature of the disease in cattle and bison.

E_1 The prevalence of tuberculosis in WBNP bison in 1997 was estimated to be 51% (63/124) based on parallel interpretation of the caudal fold and ELISA tests (Joly *et al*, 1997). This input will be represented in the model by a Beta distribution (*alpha1, alpha2*).

E_2 Transmission from wildlife to domestic animals is by the respiratory route and occurs principally when there are interactions between an excreting wildlife host and domestic animals (Morris *et al.* 1994).

E_3 The importance of the presence of *M bovis* in nasal secretions for disease transmission is well recognized (McIlroy *et al.* 1986, Neill *et al.*1988a, Neill *et al.*1988b).

E_4 M. *bovis* was isolated in nasal mucous samples from the anterior respiratory tract in 19% (7/37) (McIlroy *et al.* 1986) and 20% (5/25) (Neill *et al.*1988a) of cattle with tuberculosis confirmed by histology and culture. In a study of a herd in Argentina, 43% (42/97) of nasal secretion samples from cattle determined to be positive for TB by the caudal fold test, were culture positive for *M. bovis* (de Kantor *et al.* 1978). These inputs will be represented in the model by a weighted Discrete distribution ({*X1,X2,X3*},{*p1,p2,p3*}) with the weight of each study (*p1,p2,p3*) a proportion of the total number of samples from all three studies.

The probability of transmission of tuberculosis (T_{TB}) to at least one *At Risk* animal, given invasion and contact can be estimated by:

$$\Pr(T_{TB} \mid Invasion \cap Contact) = p \times s$$

where,

p = prevalence of tuberculosis in bison from WBNP (Beta (64,62))
s = proportion of *M. bovis* positive animals with positive nasal secretions
(Discrete{0.19,0.20,0.43}{0.23,0.16,0.61})

CONSEQUENCE ASSESSMENT

For Commercial Captive Bison and Cattle
HAZARD: *Brucella abortus*

E_1 The average size of a commercial captive bison herd in 1996 for the area considered in this risk assessment was 74 animals (Statistics Canada, 1996 Census of Agriculture). Using a 10% annual within-herd growth rate, the average herd size was estimated at 88 animals for 1998 (Gates, 1998). The distribution of the sex and age groups for an average herd in 1998 was considered to be 36 mature females, 3 mature bulls, 15 heifers, 7 yearling heifers, 6 two-year heifers, 15 bull calves, 3 yearling bull calves and 3 two-year bulls. For future years we used an average herd size estimate of 96 for 1999, 104 for 2000 and 113 for 2001. The minimum ratio was considered to be one bull for 10 cows. The calving rate is set at 85%. Half of the heifers were considered to be kept for replacement and herd expansion. Twenty percent of male calves were considered to be kept for breeding purposes. The rest were considered to be sold at auction at 1 year of age and either go to other farms for breeding or to a feedlot (Richter, 1998).

E_2 The average size of a cow-calf operation for the area considered in this risk assessment is 51 animals for all the years between 1998 and 2001 (Statistics Canada, 1996 Census of Agriculture). The distribution of animals in a cattle herd was considered to be 22 mature cows, 1 mature bull, 9 heifers, 5 yearling heifers 5 two-year heifers and 9 bull calves. There is no herd expansion assumed. Half of the heifers were considered to bekept for replacements. All bull calves and the rest of the heifers were considered to be sold to feedlots.

E_3 We estimated that it would take two years before a *B. abortus* infection would be detected either clinically or on serological testing. In the first year of infection after initial contact with an infected bison from WBNP and area, we estimate that 10% of animals in a herd would become infected and in the second year, 30% would become infected (Broughton, 1998). These within herd estimates apply to both captive bison and cattle farms.

E_4 The fertility of mature adults is affected by *Brucella abortus*. Infected cows and bulls are considered to be infertile for one year.

E_5 The value of a captive bison is higher in Alberta than in the rest of North America. The value of bison is set on average at $9000 for a mature bull, $7000 for a mature cow, $5300 for a two-year heifer, $4600 for a yearling heifer, $4000 for a young heifer, $1300 each for both young bulls of 1 and 2 years and $1000 for bull calves.

E_6 The value of cattle is set at $1500 for all animals in the herd to avoid underestimating the impact.

E_7 A total of 12 bison farms and 8 cattle farms would have at least one positive animal for *Brucella abortus* at the time the disease outbreak is diagnosed two years after the first animal is infected. This is based on the number of positive animals sold to other farms.

CONSEQUENCE ASSESSMENT

For Commercial Captive Bison and Cattle

HAZARD: *Mycobacterium bovis*

E_1 Same as E_1 in the Consequence Assessment for *Brucella abortus*.

E_2 Same as E_2 in the Consequence Assessment for *Brucella abortus*.

E_3 We estimated that it would take three years on average before a *Mycobacterium bovis* infection would be detected, either clinically or on post-mortem examination at slaughter. In the first year of infection after initial contact with an infected bison from WBNP and area, we considered that within a herd 3% of animals would become infected, in the second year 10% would become infected and by the third year 30% would become infected. These within herd estimates apply to both captive bison and cattle farms (Broughton, 1998).

E_4 The fertility of mature animals is not affected by *Mycobacterium bovis*.

E_5 Same as E_5 in the Consequence Assessment for *Brucella abortus*.

E_6 Same as E_6 in the Consequence Assessment for *Brucella abortus*.

E_7 A total of 15 bison farms and 11 cattle farms would have at least one positive animal for *Mycobacterium bovis* at the time the disease outbreak is diagnosed three years after the first animal is infected. This is based on the number of positive animals sold to other farms.

CONSEQUENCE ASSESSMENT

For Disease-Free, Free-Ranging Bison

HAZARDS: *Mycobacterium bovis* and *Brucella abortus*

The estimated value is for the two disease-free, free-ranging herds evaluated in this risk assessment, namely the Hay- Zama and Mackenzie Bison Sanctuary herds.

Estimating the value of wildlife and their genetic resource can be problematic as they are a "non-market good" and therefore not evaluated by regular market activity. They cannot be sold as they are protected and as there is no market for these animals, an approximation (or "proxy" value) based on the value of farmed bison value could be used. However, this market value reflects different genetics than what is present in the Mackenzie Bison Sanctuary or the Hay-Zama herds. The disease-free, free-ranging wood bison also hold a value for more than just the potential genetics.

The value of non-market goods reflect benefits people receive from goods and services not well represented on the market. Their estimation can be broken down into many parts. The first is comparing how much people would be willing to pay in order to benefit from the existence of the disease-free bisons. In this case, one could measure how much people are willing to pay to go in the Mackenzie Sanctuary to actually see wild wood bisons in their natural habitat. The second is to measure what benefits people may derive by knowing they could see the bison if they so wished without actually going there now. The third is by measuring benefits derived in knowing that the wood bison would be preserved for the future generations. The last one is the benefits a person derives by knowing that the disease-free wood bisons would continue to exist indefinitely. (Hanemann 1994)

It can be tedious to try to estimate any or all of these values. We suggest a proxy for the estimation of the value of the disease-free, free-ranging wood bisons herds which is the current expenditures by government bodies to keep disease-free, free-ranging herds free from tuberculosis and brucellosis. The drawback to this proxy is that what governments are currently spending may not accurately reflect the value society places disease-free, free ranging wood bison. This limitation may result in an underestimation of the of the value of the wood bisons and the estimate should be considered a minimum value.

Ideally, to make a complete estimation, we would add all the expenses ever incurred by the federal or territorial governments and discount their value through time. More reasonably, we suggest adding the expenditures committed for the preservation of the two herds during the period 1995-2000.

CFIA - Testing and surveillance	$2,500,000
Canadian Heritage - Research	2,500,000
Government of the NWT	350,000
Total for the period 1995-2000:	$5,350,000

RISK ESTIMATION

Computer simulation of the mathematical model used to estimate the risk of infection with *Brucella abortus* or *Mycobacterium bovis* from bison in WBNP and area in a 12 month period, for each of three identified At Risk groups; cattle, commercial captive bison, free-ranging disease-free bison, was carried out with 10,000 iterations using the software @RISK (Palisade Corporation, Neufield, New York).

The risk is estimated by the model: $I \times C \times T \times E$
where,

I = Probability of Invasion
C = Probability of Contact | Invasion
T = Probability of Transmission | Invasion ∩ Contact
E = Consequences | Invasion ∩ Contact ∩ Transmission

Risk of Brucellosis and Tuberculosis for Commercial Captive Bison

Based on the model employed, in 1998 there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with bovine brucellosis is less than 4.36×10^{-3} if the geographic distribution and number of commercial bison farms and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 229 years if populations and distributions remain at 1998 levels.

The monetary consequences of a brucellosis infection in commercial captive bison would total approximately $6.5 million per incursion or $28,384 for every year between outbreaks.

And, in 1998 there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with tuberculosis is less than 5.77×10^{-3} if the geographic distribution and number of commercial bison farms and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 173 years if populations and distributions remains at 1998 levels.

The monetary consequences of a tuberculosis infection in commercial captive bison would total approximately $8.2 million per incursion or $47,399 every year between outbreaks.

Risk of Brucellosis and Tuberculosis for Cattle

Based in the model employed, there is a 95% probability that the estimated annual probability of at least one bovine becoming infected with brucellosis is less than 7.84×10^{-4}. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 1,276 years.

The monetary consequence of a brucellosis infection in cattle would total approximately $632,000 per incursion or $495 every year between outbreaks.

And, there is a 95% probability that the estimated annual probability of at least one bovine becoming infected with tuberculosis is less than 5.67×10^{-4} . In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 1,764 years.

The monetary consequence of a tuberculosis infection in cattle would total approximately $832,000 per incursion or $472 every year between outbreaks.

Risk of Brucellosis and Tuberculosis for Disease-Free, Free-Ranging Bison

Based on the model employed, in 1998 there is a 95% probability that the estimated annual probability of at least one free-ranging bison becoming infected with bovine brucellosis is less than 0.12, if the geographic distribution and number of bison in free-ranging herds and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 8 years if populations and distributions remain at 1998 levels.

The monetary consequences of a brucellosis infection in disease-free, free-ranging bison would total approximately $5.4 million per incursion or $668,750 for every year between outbreaks.

And, in 1998 there is a 95%probability that the estimated annual probability of at least one free-ranging bison becoming infected with tuberculosis is less than 0.16, if the geographic distribution and number of bison in free-ranging herds and diseased herds remains constant. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 6 years if populations and distributions remains at 1998 levels.

The monetary consequences of a tuberculosis infection in disease-free, free-ranging bison would total approximately $5.4 million per incursion or $891,667 every year between outbreaks.

ANALYSIS OF BISON SIGHTINGS

QUALITATIVE EVALUATION OF BISON SIGHTING DATA

Data on bison sightings was analyzed for an empirical evaluation of the invasion probability model developed using WBNP telemetry data previously described. Databases were supplied by Dr. Cormack Gates, compiled while with Resources Wildlife & Economic Development, Government of the North West Territories (NWT) and by David Moyles a Wildlife Biologist with Natural Resource Service, Alberta Environmental Protection and included sightings from 1970 to 1998. Information recorded includes date, number and description of the bison observed, latitude and longitude of the sighting and identification of the person(s) reporting the sighting.

Sightings observed from 1990 to the present were analyzed. We considered that the 22 sightings recorded prior to 1990 (Map 3) were not relevant to the current situation due to the decline in bison population in and around WBNP after 1989. The software program GIS Atlas (ESRI, 1994) was used to plot the observed sightings. Our analysis focused on sightings in the area west and south of WBNP and excluded sightings located in the bison control areas, within WBNP or within what we have identified as the normal home range of known diseased herds. The remaining subset of bison sightings represented bison that we have considered to have traveled outside of their normal home range.

Database

Analysis of the combined databases (Map 2) revealed three bison sightings in the developed Fort Vermilion/La Crete area between 1989 and 1998. Two sightings were made west and south of High Level, just outside the Alberta Bison Management Zone. In 1994, two bulls were seen about 10 kms west of the Alberta Bison Management Zone in September 1994. The two bulls were eliminated. Two bison sighted in 1995 were seen eight km south of High Level. Because of location we considered these four bison to be from the Hay Zama herd and therefore assume them to be disease-free bison. In 1997 a sighting of one bison was made north of Beaver Ranch. In summary, for the developed Fort Vermilion/La Crete area, the analysis of the bison sightings databases showed that only one bison per year from the WBNP area (and therefore potentially infected) has traveled into the developed Fort Vermilion/La Crete area over the time period 1989 to 1998. Using a detailed census district map (Alberta Environment Protection Provincial Base Map, 1995), we considered the "developed" Fort Vermillion/La Crete area to be the area in MD 23 with additional grid lines, extending as far south as just north and east of the Carcajou Settlement Indian Reserve. See Map 1 "Developed areas".

Outside of the developed Fort Vermilion/La Crete area, there were 14 sightings made since 1989 which were outside of WBNP and were not considered to be sightings of bison from the Wabasca herd. Two sightings of 19 animals were made in the same year two weeks and approximately 20 kms apart, with the latter sighting close to the park border. We considered these two sightings to be the same group of bison. There were approximately 30 sightings made North and West of High Level. Because of their location, these were considered to be bison from be from the Hay Zama Herd and therefore to be disease-free bison. Three sightings were made in the area recognized to be the normal home range of the Wabasca herd. The total number of animals observed in the 14 sightings outside of the developed Fort Vermilion/La Crete area and outside of WBNP and the normal home range for the Wabasca Herd was 72 bison or 7.2 bison per year.

The overall total of bison outside WBNP and the normal home range of the Wabasca herd is 73 or 7.3 bison per year. In other words, on average over the last 10 years, 7.3 bison were sighted each year in the area outside the bison control areas, WBNP or what we have identified as the normal home range of known diseased herds.

Conclusion

Our invasion probability model predicts with 95% confidence that at most invasion into the Fort Vermilion/La Crete area would occur less than once every 2.9 years This is higher than what would be predicted by empirical means as there was one (1) sighting of a single bison suspected to be from WBNP and area made in the developed Fort Vermilion/La Crete area in the past 10 years. We expect that bison sightings are likely under-reported. There were no campaigns actively to encourage people to report sightings. We would also expect, however, less under reporting in the Fort Vermilion area because the concentration of human population of this area.

QUANTITATIVE EVALUATION BISON SIGHTINGS DATA

Based on bison telemetry data from WBNP, we have derived mathematical models for the extremes in bison movement pattern. There is some concern that our models may tend to underestimate the actual risk because mature adult males may have been under-represented by the WBNP telemetry data. At the recommendation of Dr. Cormack Gates and others, we have undertaken to evaluate the accuracy of the telemetry-data-driven model by comparing it with another database, namely the bison sighting data cumulated in past 10 years from roughly the same area.

Methodology:

1. We have tallied all sightings of free-ranging bison in the area of concern and these total 73 incidents in 10 years. We have also examined all historical herd sizes from all source herds that may have contributed to these sightings over this nine year period. These give us a total of 27,755 bison-years (10 year total).

2. The exact location of the reported sightings varied substantially within the area. To avoid complex mathematical models and the theoretical assumptions required therewith, we estimated the average traveling distance to the sighted location from the bison's most likely home range. This estimated average traveling distance is 58 km.

3. The mathematical model we have derived from telemetry data is then used to estimate the expected total number of incidents of bison traveling to this distance from their normal home range in the total number of bison-years covered by the sighting data. This number is 7,867 bison.

4. However, the above represents the incidents in all directions, many of which would not be covered by the reported sightings. After examining the geographic distribution of human communities in the area, we estimate that at least one fourth of the extreme bison travels would have come in directions for which sighting was likely.

5. The combination of three 3 and 4 then gives us the expected total number of sightings for the last 10 years at the average distance of the reported sightings, assuming that a bison coming into the "reporting area" was always sighted. This expected number is 1,967 bison, much higher than the reported number of sightings namely 73 bison.

Conclusion:

A quantitative evaluation comparing the number of bison actually sighted to the number of bison the model predicts showed that, on average, not more than 3.7% of bison intrusions predicted by our risk model were actually spotted and reported. In other words, the model predicted many more bison would travel into the area where they would be a risk source that were actually observed. In our view, this reflects a rather reasonable, if not overly conservative, risk assessment. In summary, our model does not appear to have underestimated the risk of extreme bison movement.

TEMPORAL MODELING:

Five and Ten year Projections for Commercial Captive Bison

Methodology

Annual growth in commercial bison farms of has been estimated to be 25% (Hussey 1997). This gives a five (5) year projection of 1,008 commercial bison operations in the year 2,003 and a ten (10) year projection of 2,028 commercial bison operations in the year 2,008. In this model, we considered the geographic distribution of the commercial bison operations to remain as they are in 1998.

The economic consequences are estimated in 1998 dollars to help in comparing the different scenarios. It is important to note that predicting the impact in 5 or 10 years without adjusting for farm demographics and price may overestimate the impact. The estimates do not reflect the direct cost of controlling the outbreak.

Risk of Brucellosis and Tuberculosis in Five Years

Based on the model employed, in five (5) years there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with bovine brucellosis is less than 7.87×10^{-3}. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 127 years.

The monetary consequences of a brucellosis infection in commercial captive bison 5 years in the future, based on the assumptions described above, would total approximately $13.1 million per incursion (with 18 farms infected) or $103,150 for every year between outbreaks.

And, in five (5) years there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with tuberculosis is less than 1.14×10^{-2}. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 87.8 years.

The monetary consequences of a TB infection in commercial captive bison 5 years in the future, based on the assumptions described above, would total approximately $19.4 million per incursion (with 22 farms infected) or $220,455 for every year between outbreaks.

Risk of Brucellosis and Tuberculosis in Ten Years

Based on the model employed, in ten (10) years there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with bovine brucellosis is less than 1.05×10^{-2}. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 63.83 years.

The monetary consequences of a brucellosis infection in commercial captive bison 10 years in the future, based on the assumptions described above, would total approximately $31.6 million per incursion (with 27 farms infected) or $493,750 for every year between outbreaks.

And, in ten (10) years there is a 95% probability that the estimated annual probability of at least one commercial captive bison becoming infected with tuberculosis is less than 2.28×10^{-2}. In other words, one can state with 95% confidence that on average the introduction of infection would occur no more frequently than once every 43.91 years.

The monetary consequences of a TB infection in commercial captive bison 10 years in the future, based on the assumptions described above, would total approximately $46.9 million per incursion (with 35 farms infected) or $1,065,909 for every year between outbreaks.

SHORT DISTANCE MODEL:

The Probability of Invasion at Close Proximity to Diseased Herds

Discussion

A major concern of this risk assessment has always been the rare, extreme bison movement outside their normal home range. For this we have analyzed the maximum annual range of bison based on WBNP telemetry data and extended or extrapolated the telemetry data-driven distribution to distances much beyond the observed maximum home range.

A technical condition, though not always explicitly mentioned, is that the probabilities involved are all very small, reflecting the rare nature of the events of concern. This condition may no longer hold true when we move closer and closer to the normal bison home range. In particular, the probability of multiple occurrences of a peripherally "rare" event would no longer be negligible. Our existing model can be adjusted to some extent to accommodate multiple occurrences, but we feel that, a model developed for extreme movement would not be appropriate for movement near and within the normal home range.

For possible application within normal home range and its near peripheries, as well as a check of the "extreme-movement" model, we have developed an alternative model, still using on the WBNP telemetry data but based on "regular" bison movements.

Methodology

This new model is based on classical grid-cell approach and "occupation time". A brief synopsis of model is given as follows:

1. We first analyzed the normal bison movement pattern in terms of distance from a bison's annual "center of activity". Based on the telemetry data, this distance turns out fairly well modeled by a gamma distribution.

2. Using the above distribution, the relative amount of time spent by a bison in various home range "rings" in a year can be estimated. This can be expressed in number of days.

3. Telemetry data are again used to calculate the average "linear movement" speed of bison.

4. Given the linear speed, we can estimate the average "occupation time", say in number of days, of a grid-cell of a specific size, by calculating the average time required for a bison to travel across the cell.

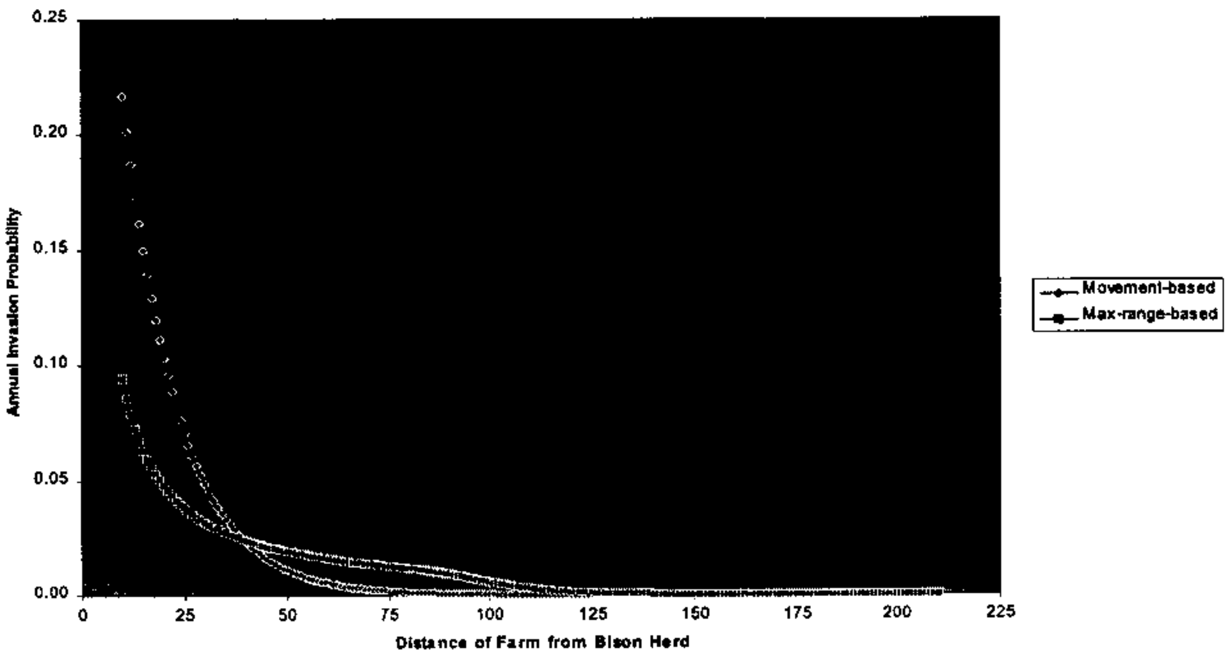
5. For a particular area, say a cattle farm, near or inside a bison herd territory, we can estimate the bison invasion (or rather bison visiting) probability by first constructing a herd home range "ring", in which the area of concern is located. We then divide the ring into grid cells of the size of the area of concern.

6. We then calculated the total occupation time in bison-days of the range ring from the entire herd in a year, as well as the average occupation time of the defined grid-cell. In the end, we will be able to estimated the expected number of grid cells occupied (or rather visited) by any bison from the herd, with the understanding that some cells will be visited more than once.

7. Using a simplified "random visit" assumption, we can then estimate the annual invasion probability, which is the probability that the "farm cell" is visited at least once during the year. It is understood that the "random visit" assumption ignores autocorrelations and inter-bison correlations that may exist. But it may also be argued that these correlations would mainly lead to an increase in variability ("over-dispersion"), rather than substantially change the average.

We have carried out the above modeling, and used it to estimate and compare the invasion probability with the previous "extreme movement-based" model. See Graph 1: Annual Invasion Probability for one diseased herds, the Wabasca herd.

Graph 1: Wabasca Herd



Results for the Wabsaca Herd
Note that the annual invasion probability will be the cumulative probabilities for all six (6) disease herds. In Graph 1 we present the annual invasion probability for one diseased herd, the Wabasca herd. Examples of mean annual invasion probabilities for the Wabasca herd are: 0.22 at 10 km (once every 4.5 years), 0.15 at 15 km (once every 6.7 years), 0.10 at 20 km (once every 10 years) and 0.07 at 25 km (once every 14.3 years).

Conclusion
The results show that in the near peripheries, up to about 30-50 km from the herd territory, the "movement based " model provides higher invasion probability estimates; but beyond that, the "max-range based" (ie. based on the telemetry data and therefore a prediction of extreme movement) model prevails and gives a higher probability estimate.

In summary, the alterative model confirms that our previous model does not underestimate the bison invasion probability beyond the immediate surrounding areas of a bison herd.

REFERENCES

Broughton E. (Disease Control Officer, AHD, CFIA) March 24, 1998. Personal communication.

Chisholm J. (Parks Canada, Bison Research & Containment Program) March 19, 1998. Personal communication.

Copeland R. (District Veterinarian for Grand Prairie), Patton D. (Bison Producer), Moore N. (Bison Producer) February 1998. Personal communication.

Davis S.D., Templeton J.W., Ficht T.A., Williams J.D., Kopec J.D., Adams L.G. (1990). *Brucella abortus* in captive bison. I. Serology, Bacteriology, Pathogenesis, and Transmission to Cattle. Journal of Wildlife Diseases. 26(3):360-371.

de Kantor I. N., Bioch D., Roswurm J.D. (1978) Mycobacteria Isolated from the Nasal Secretions of Tuberculin Test Reactor Animals. American Journal Veterinary Research. 39: 1233-1234.

Dobson A., Meagher M. (1996) The population dynamics of Brucellosis in the Yellowstone National Park. Ecology. 77(4): 1026-1036.

Gates C. Received 1997. Unpublished Database: Bison Farm location (UTM Coordinates)

Hanemann, W.M. (1994) Valuing the Environment Through Contingent Valuation. Journal of Economic Perspectives 8(4):19-43.

Hussey G. (1997). Hussey & Kilpatrick Associates. Analysis carried out for the Alberta Bison Association: Value of Bison Production 1997 Estimates for Alberta.

Joly D.O., Leighton F.A., Messier F. (1997). Tuberculosis and Brucellosis Infection of Bison in Wood Buffalo National Park, Canada: Preliminary Results. Unpublished document from the University of Saskatchewan and Western College of Veterinary Medicine.

McCorquodale S.M., DiGiacomo R.F. (1985). The role of wild North American Ungulates in the epidemiology of bovine brucellosis: A review. Journal of Wildlife Diseases. 21(4): 351-357.

McIlroy S. G., Neill S. D., McCracken R.M. (1986). Pulmonary lesions and *Mycobacterium bovis* excretion form the respiratory tract of tuberculin reacting cattle. Veterinary Record. 118: 718-721.

McLeod D. M., Van Tassell L. W. (1996). Economic and Policy Implications of Brucellosis in the Greater Yellowstone Area. Rangelands 18(4):145-148.

Morris R. S., Pfeiffer D.U., Jackson R. (1994) The epidemiology of *Mycobacterium bovis* infections. Veterinary Microbiology 40: 153-177.

Neill S.D., O'Brien J. J., McCraken R.M. (1988). *Mycobacterium bovis* in the anterior respiratory tracts in the heads of tuberculin-reacting cattle. Veterinary Record. 122: 184 -186.

Neill S.D., Hanna J., O'Brien J. J., McCraken R.M. (1988b). Excretion of *Mycobacterium bovis* by experimentally infected cattle. Veterinary Record. 123: 340-343.

Neilsen K.H., Kelly L., Gall D., Baslevicius S., Bosse J., Nicolleti P., and Kelly W.. (!996) Comparison of enzyme immunoassays for the diagnosis of bovine brucellosis. Preventive Veterinary Medecine. 26:17-32.

Pauls R. February 1998. Senior Environmental Associate, Syncrude Tar Sands Restoration Project. Personal communication.

Plant J. W., Claxton P.D., Jakovljevic D., Marburg M.B., de Saram W. (1976) *Brucella Abortus* Infection in the Bull. Australian Veterinary Journal. 52:17-20.

Quist W. Private Practitioner Fort Vermilion. February 1998. Personal communication.

Radostits O.M., Blood D. C., Gacy C.C. *eds.* (1994) Brucellosis caused by *Brucella abortus* (Bang's Disease) in Veterinary Medicine. A textbook of Disease of Cattle, Sheep, Pigs, Goats and Horses. Eight Edition. Bailliere Tindall, London.

Stemshorn B.W., Forbes L.B., Eaglesome, M.D., Nielsen K.H., Robertson F.J. and Samagh B.S. (1985) A comparison of standard serological tests for the diagnosis of bovine brucellosis in bison in Canada. Canadian Journal of Comparative Medecine. 49:391-394.

Richter, G. (Canadian Bison Association) March 26, 1998. Personal communication.

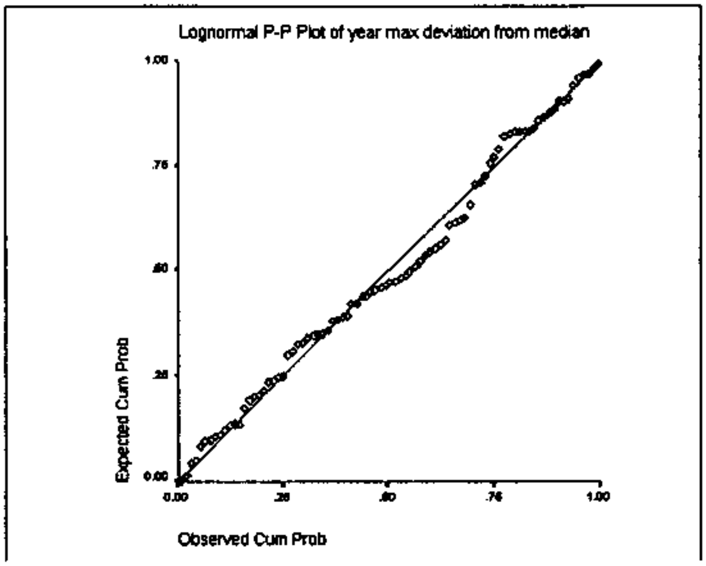
Uzal F.A., Carrasco A.E., Echaide S., Neilsen K. and Robles C.A. (1995) Evaluation of an indirect ELISA for the diagnosis of bovine brucellosis. Journal of Veterinary Diagnostic Investuigation. 7:473-475.

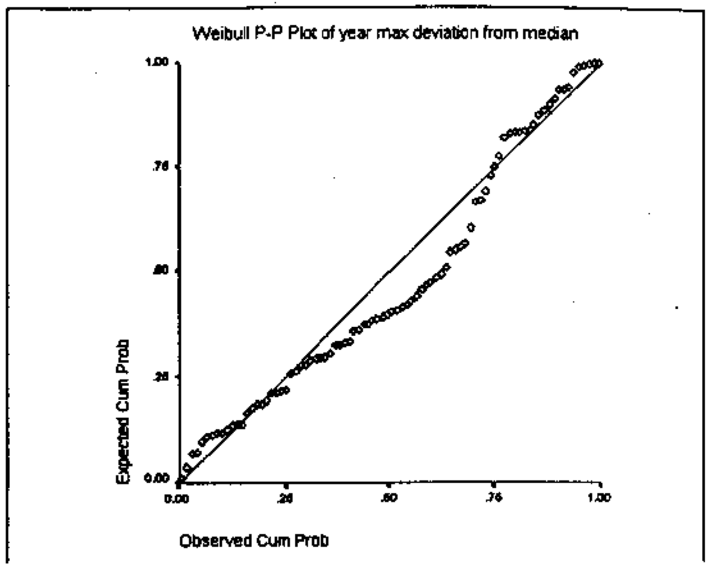
Wood Buffalo National Park (1995). Bison movement and distribution study final report. Technical Report 94-08WB, Wood Buffalo National Park, Box 750, Fort Smith, NT, X0E 0P0.

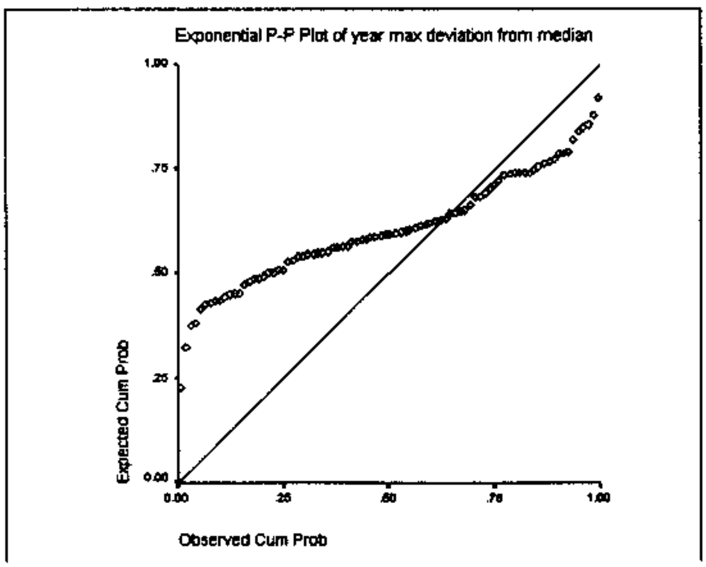
Sections to be completed:

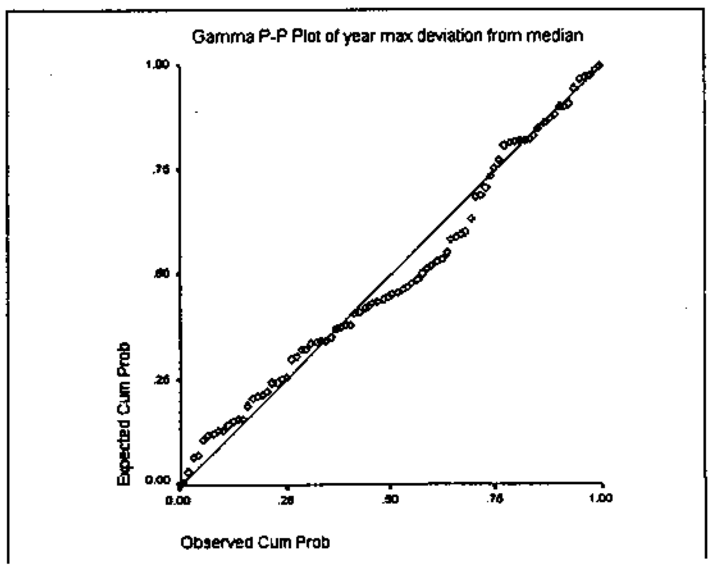
1. Sensitivity Analysis
2.. Recommendations for further research
3. Description of the limitations of the risk assessment

APPENDIX A: Telemetry Data Points Fit to Distributions



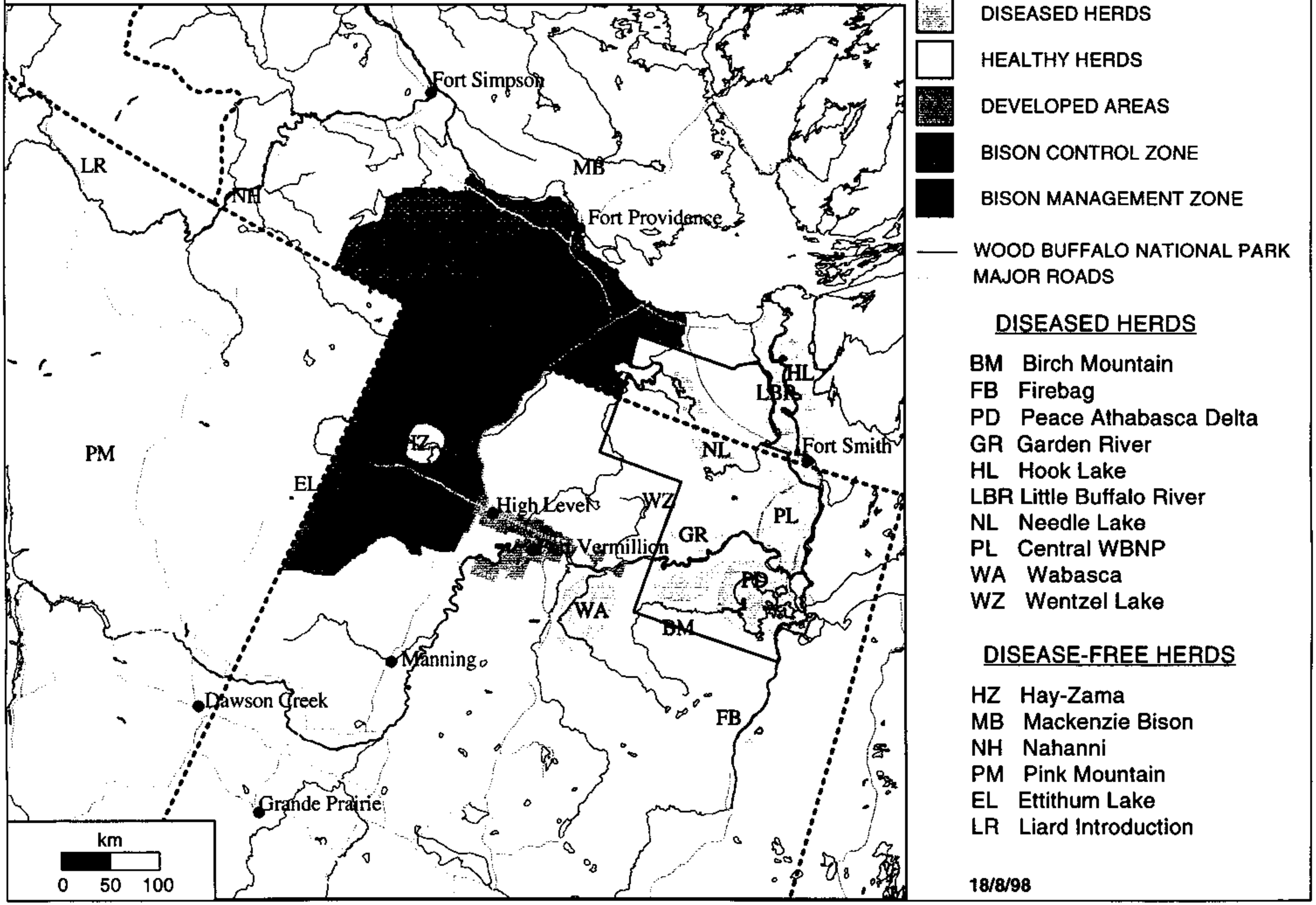






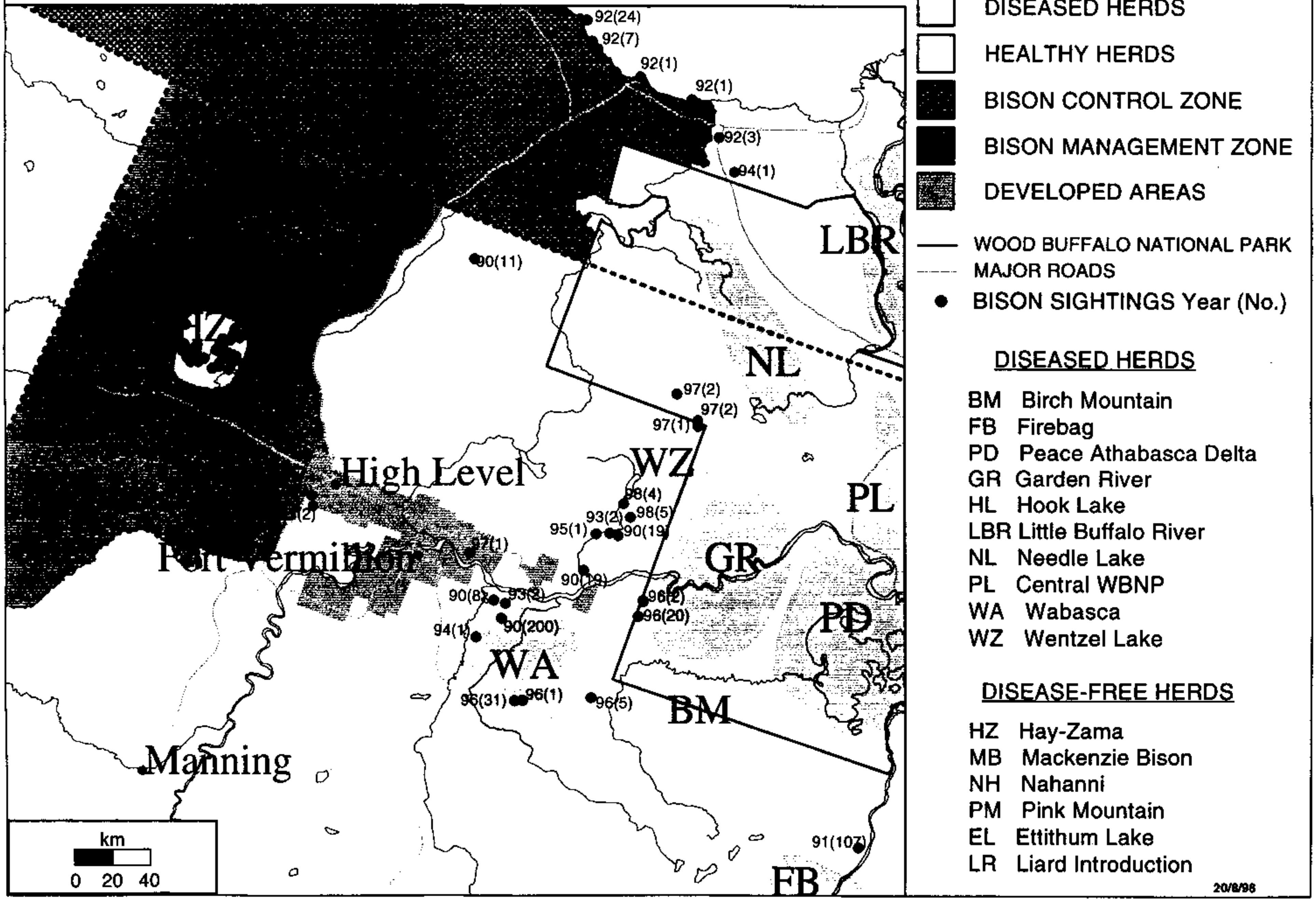
MAP 1: FREE-RANGING BISON IN CANADA

Locations of Diseased and Disease-Free Herds



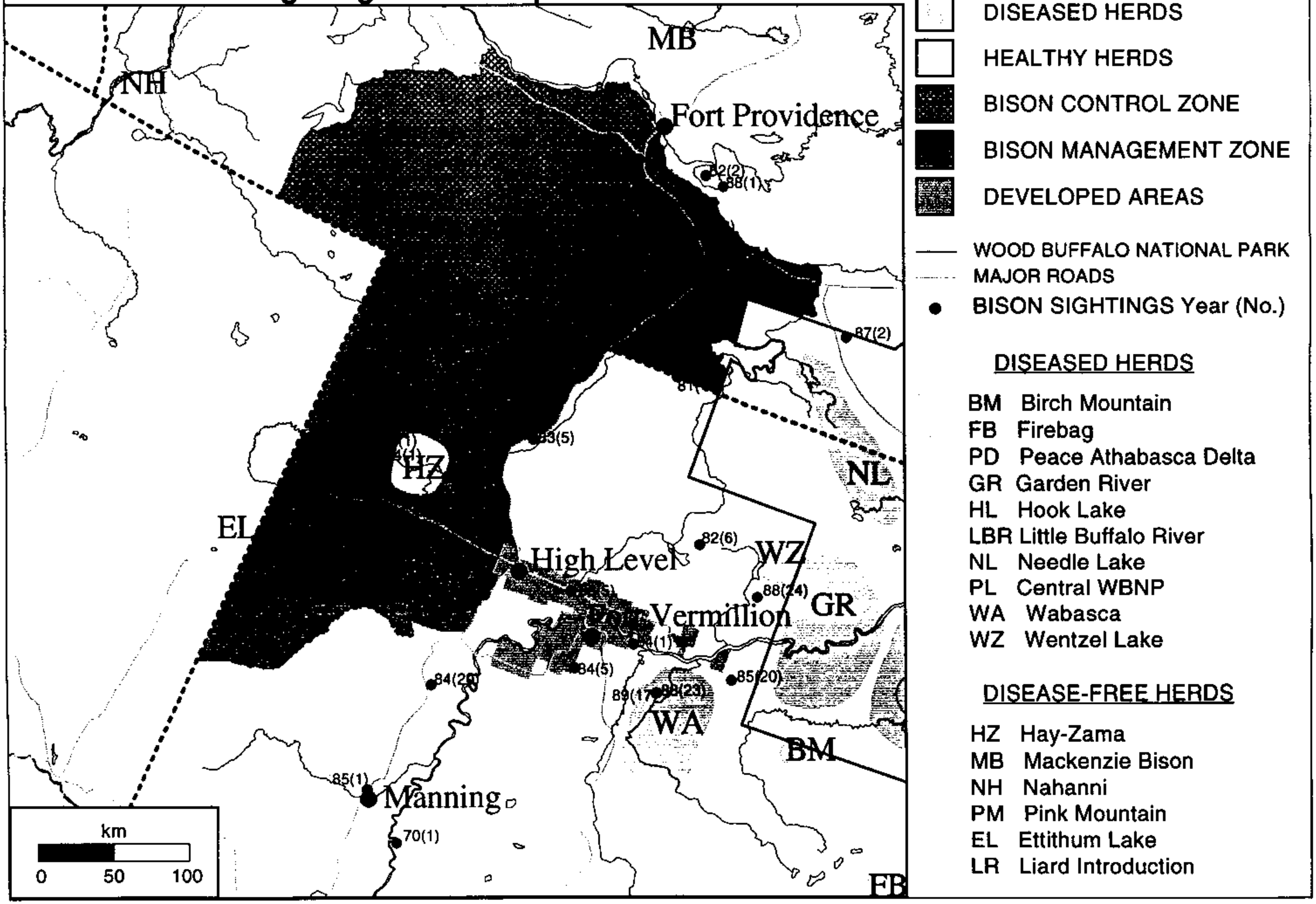
MAP 2: FREE-RANGING BISON IN CANADA

Sightings of bison 1990 - 1998



MAP 3: FREE-RANGING BISON IN CANADA

Sightings of bison prior to 1990



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