Proceedings of the Bison Diseases Technical Workshop

Co-Sponsored by the Parks Canada Agency and the Canadian Wildlife Service

Hosted by the Alberta Cooperative Conservation Research Unit (ACCRU)

Environment Canada Environnement Canada

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Foreword

This report summarizes the results of a technical workshop held at the University of Alberta in October 2005. The workshop was designed to answer a very specific technical question: "Could bovine tuberculosis and brucellosis be eliminated from free-roaming herds of bison in the region centered on Wood Buffalo National Park, through a program of depopulation and subsequent repopulation?" Inherent in answering this question were a set of assumptions, as follows:

Successful depopulation and repopulation means re-establishing bison to similar population levels without any significant loss in genetic diversity.

Any depopulation / repopulation scenarios must have a high probability of eliminating both bovine tuberculosis and brucellosis.

The technical question of "can the diseases be eliminated?" is distinctly different from the broader policy question of "should the diseases be eliminated through depopulation and repopulation?"

This broader policy question needs to be answered by a larger group representing a wider range of interests. The technical workshop specifically avoided the broader policy question. However, we believe that it is essential to answer the technical questions prior to addressing the broader policy question.

Bison are an iconic species in Canada. The subject of depopulating a free-roaming herd of large herbivores, especially bison, is extremely controversial. The organizers recognize this controversy, but believe an answer to the technical feasibility of disease eradication is necessary to inform the broader policy questions surrounding the issue. The workshop was thus kept strictly focussed on technical issues and participation was limited to a technical and scientific group. There were 32 participants at the workshop, representing a range of federal, provincial and territorial government departments and agencies, universities, and international invited guests who were experts in technical and scientific elements of the issue (see List of Workshop Participants on p.14).

The summary results of the technical workshop are as follows:

1. There was a unanimous consensus that the eradication of bovine tuberculosis and brucellosis through depopulation and repopulating bison in the Wood Buffalo region is technically feasible. Done under tightly controlled conditions, there would be a very high probability of eradicating both diseases.

2. The eradication of these diseases would be a long-term project, taking 15-20 years. The depopulation phase would take 10 years but the repopulation phase could be done more quickly.

3. Technical success for this project was defined as re-establishing a disease-free bison population at a similar level to the current population without any loss in genetic diversity.

4. The cost for the technical project was estimated to be between 62 and 78 million dollars over 20 years with the greatest costs being incurred during the first 4 years. These costs include a wide range of ecological monitoring costs.

This workshop report is freely available to all interested parties and will be made available to anyone with an interest in the northern bison disease management issue. The organizers hope the workshop will assist in answering the broader policy question surrounding these complex issues.

Stephen Woodley (email: stephen.woodley@pc.gc.ca)
Workshop Facilitator
Parks Canada
December 2005

Executive Summary (English)

This workshop set out to define the conditions under which bovine tuberculosis and brucellosis could be eradicated from Wood Buffalo National Park and surrounding area through depopulation of diseased wood bison and repopulation with healthy bison. This is the disease eradication strategy recommended by the 1990 Federal Environmental Assessment Review Office panel. Thirty-two technical experts attended the two-day workshop from Canada, the United States, New Zealand and Australia including veterinarians, biologists, ecologists and ecological modellers. The meeting was co-hosted by the Parks Canada Agency and the Canadian Wildlife Service, Environment Canada and was hosted by the Alberta Cooperative Conservation Research Unit at the University of Alberta in Edmonton.

Three primary Breakout Groups were chosen to attempt to define the issues surrounding 1) depopulation, 2) repopulation and genetic salvage, and 3) ecological implications of depopulation and repopulation.

Depopulation was considered feasible over a time frame of approximately ten years, based on published criteria, population modelling and experience from other similar programs. The only means to assure that bovine tuberculosis and brucellosis are eradicated from wood bison within the Wood Buffalo National Park area is to completely depopulate the area of bison, allow for a bison-free period and begin repopulating from specific disease-free source herds outside the area. Corral-traps were considered to be the most efficient method for removing a large number of animals in the initial stages of depopulation, but this capture method may also be efficient throughout much of the project. After initial trapping of a large percentage of the population, shooting from both the ground and from the air would be an essential component to depopulation. This technique would utilize experience from local communities as much as possible. The success of shooting would be enhanced by, 1) using sliding-scale bounties to encourage hunting and 2) setting up hunting camps for local hunters. Most of the depopulation effort should occur during winter and would employ aerial tracking using radio-collared "Judas" animals as well as advanced technology (e.g. satellite or infrared images) for finding animals. Every attempt should be made to remove bison carcasses from the landscape because of the potential risks associated with disease transmission to secondary hosts (e.g. wolves, deer) and because of the unknown and potentially negative ecosystem consequences (e.g. increase in scavenger or predator populations). Using Judas animals was considered to be an effective method to help find small herds or individual animals in conjunction with surveys that would be conducted to ensure the last remaining animals were removed. The Hay Zama and Mackenzie Bison Sanctuary wood bison populations must be tested for the presence of bovine tuberculosis and brucellosis and, if positive, for either disease, they must be included in the depopulation. Assuming that the Mackenzie and Hay-Zama populations were disease-free, the total cost of a depopulation scenario would range between $35 and $50 million dollars.

Once depopulation is considered complete, repopulation could be achieved by introducing at least 1,000 animals (calves and yearlings) over a period of three to four years. The bison in the reintroduction population would propagate at the same time as depopulation was occurring. This would be accomplished through the use of off-site breeding stations established with wood bison

from Elk Island National Park as well as disease-free animals salvaged from within Wood Buffalo National Park, which is the most genetically diverse population of wood bison. Two 'Soft releases' (holding of newly translocated animals in corrals while they acclimatize) of bison in February or March in two releases of 500 animals each would be the preferred method of reintroduction. Since Wood Buffalo National Park has the most genetically diverse population of wood bison, salvage of wood bison genetics from the Park was determined to be essential to any disease eradication program. Genetic salvage could be accomplished through either live animal salvage or by using advanced reproductive techniques adapted from cattle for use in bison. Further research is required to adapt techniques developed in cattle such as *in vitro* fertilization, superovulation and cryopreservation of sperm and ova for use in bison and to validate live animal salvage protocols (wood bison tuberculosis salvage protocol). The goal would be to salvage between 95% and 100% of the genetic diversity currently present within the Wood Buffalo metapopulation through salvage of at least 200 individual bison. It is projected that the area could be repopulated to current levels (approximately 4,500 bison) within a 10-year period.

In developing a protocol for the eradication of bovine tuberculosis and brucellosis, the workshop also considered other diseases, such as paratuberculosis (*Mycobacterium avium paratuberculosis* (MAP). The workshop concluded that other diseases were not a concern for free-ranging bison. In particular, MAP does not seem to cause clinical disease in free-ranging bison and will not likely be a future issue because of its ubiquitous nature in many species. Introduction of bovine viral diarrhea was considered undesirable in reintroduced bison.

One concern associated with the depopulation/repopulation scenario is the potential loss of learned behaviors beneficial to survival in the Wood Buffalo region. There was consensus that any loss of learned behaviors would not be permanent and could be re-learned within a short time frame. Furthermore, significant innate behaviors would be conserved through genetic salvage.

Total cost for repopulation and genetic salvage was estimated to be approximately $14 million.

Ecological implications of depopulation and repopulation were initially discussed within the context of a simulation model being developed by the University of Ottawa (Patrick Boily and Scott Findlay). This model could be used to predict the temporal and spatial changes in density and distribution of bison, caribou, moose and wolves during the depopulation/repopulation period and possible changes in specific habitats because of the removal of a key herbivore from the ecosystem. Because the model is still under development, the Breakout Group focused on identifying model parameters as well as a set of possible undesirable outcomes of the bison depopulation/repopulation. These non-modeled outcomes included the potential effects on species at risk, long-term structural changes in vegetation communities, long-term population and/or genetic change in specified vertebrate populations, and the potential loss of bison-associated invertebrate species. It was widely believed that a ten-year depopulation period and an approximately ten-year repopulation period is unlikely to result in undesirable ecosystem cascades that could result in local extinction of species. Revisions were suggested to the model including that a BACI (Before/After – Control/Impact) experimental design be employed to test model predictions and to determine how species and habitats will interact in the face of depopulation/repopulation. It was also recommended that a 25 km^2 grid cell size be the basis for modelling using four seasonal time steps with a total time horizon of 20 years. It was agreed that the model should be concerned primarily with an assessment of the likelihood of “undesirable” and “intolerable” outcomes, identified as: (1) reductions in abundance of species at risk; (2) longer-term changes in important vegetation communities, especially loss or dramatic decline in meadow habitat quality by intrusion from exotic weeds; (3) post-repopulation bison irruptions; (4) very low or very high wolf densities; (5) low moose or beaver abundance; (6) substantial increases in scavenger populations, particularly black bear and ravens; and (7) loss of obligate bison-associated invertebrates. It is important that the model retain sufficient flexibility to accommodate novel scenarios that may arise during the implementation phase and that adaptive management be included as an important component of the implementation strategy. The total cost of model redesign, a twenty-year program of vegetation and ecosystem component monitoring and mitigation costs was estimated to be approximately $13.5 million.

In conclusion, the workshop participants were unanimous in their agreement that disease eradication through a depopulation/repopulation scenario as discussed and laid out was technically feasible, providing that adequate resources, funding and a management infrastructure able to carry out a twenty-year program would be available. There was further consensus that the National Wildlife Disease Strategy approved by Wildlife Ministers in October 2005 should be used as a framework for coming to some kind of resolution for the bison disease issue in northern Canada.

Résumé (Français)

L’atelier visait à définir les conditions d’éradication de la tuberculose bovine (TB) et de la brucellose dans le parc national Wood Buffalo (PNWB) et la région environnante, par le dépeuplement des bisons des bois atteints et leur remplacement par des animaux sains, conformément à la stratégie d’éradication de la maladie recommandée par la Commission fédérale d’examen des évaluations environnementales (1990). Trente-deux experts – des vétérinaires, des écologistes, des biologistes et des experts en modélisation écologique du Canada, des États-Unis, de la Nouvelle-Zélande et de l’Australie – ont assisté à l’atelier de deux jours. La réunion était organisée par l’Agence Parcs Canada et le Service canadien de la faune d’Environnement Canada, et s’est tenue à l’Université de l’Alberta, à Edmonton, sous les auspices de la Alberta Cooperative Conservation Research Unit.

On a créé trois principaux groupes de discussion pour tenter de définir les questions entourant 1) le dépeuplement, 2) le repeuplement et la récupération du matériel génétique et 3) les conséquences écologiques du dépeuplement et du repeuplement.

À partir de critères établis, de la modélisation des populations et de l’expérience tirée d’autres programmes semblables, on a jugé que le dépeuplement était faisable sur une période d’environ 10 ans. Le seul moyen de veiller à ce que la tuberculose bovine et la brucellose qui touchent le bison des bois soient éradiquées du secteur du parc national Wood Buffalo (PNWB) est d’éliminer toute la population de bisons, de laisser s’écouler un certain temps pendant lequel on ne trouverait aucun bison dans le secteur, puis de commencer à réintroduire des bisons à partir de hardes spécifiques situées à l’extérieur du secteur. Au cours des premiers stades de dépeuplement, les corrals constitueraient la méthode la plus efficace pour capturer un grand nombre d’animaux, mais ils pourraient également s’avérer efficaces pendant la presque totalité du projet. Après le piégeage initial d’une grande partie de la population, la chasse – à partir du sol ou des airs – constituerait un élément essentiel du dépeuplement. Dans ce domaine, on utiliserait autant que possible l’expérience des communautés locales. Le succès de cette méthode tiendrait en partie à 1) l’attribution de récompenses variables pour encourager la chasse et 2) à l’établissement de camps de chasse pour les chasseurs de la région. L’opération de dépeuplement devrait être effectuée principalement pendant l’hiver et il faudrait utiliser le repérage aérien, des « mouchards » (animaux équipés d’un émetteur radio) ainsi que des technologies avancées (p. ex. images satellites ou infrarouges) pour trouver les animaux. Il faudra tout faire pour éliminer les carcasses des bisons, à cause des risques de transmission de maladies à des hôtes intermédiaires (p. ex. loups, chevreuils) et des conséquences inconnues et potentiellement négatives sur l’écosystème (p. ex. augmentation des populations de charognards ou de prédateurs). L’utilisation d’animaux « mouchards » a été jugée utile pour trouver des hardes de taille réduite ou des individus, en conjonction avec les recherches menées pour s’assurer que les animaux ont été éliminés jusqu’au dernier. On devra soumettre les populations de bisons des bois de Hay Zama et de la Réserve de bisons du Mackenzie à des tests pour vérifier la présence de la tuberculose bovine et de la brucellose; si ces tests sont positifs pour l’une ou l’autre maladie, il faudra inclure les populations concernées dans les opérations de dépeuplement. Si on présume que les populations du Mackenzie et de Hay Zama sont saines, on peut estimer le coût total d’un scénario de dépeuplement entre 35 et 50 millions de dollars.

On pourrait effectuer le repeuplement en introduisant au moins 1 000 animaux (veaux et animaux d’un an) sur une période de trois ou quatre ans, après la fin du dépeuplement. Les bisons constituant la population de remplacement se reproduiraient au rythme du dépeuplement, grâce à l’utilisation de bisons des bois provenant de stations d’élevage extérieures situées dans le parc national Elk Island, ainsi que d’animaux sains récupérés dans le PNWB, dont la population de bisons des bois possède le matériel génétique le plus diversifié au monde. Deux « mises en liberté progressives » (maintien des animaux déplacés dans un corral, le temps de leur permettre de s’acclimater) des bisons en février ou en mars, en groupes de 500 animaux chacun, constitueraient la meilleure méthode de réintroduction. Étant donné l’exceptionnelle diversité génétique du bison des bois du parc national Wood Buffalo, on a jugé la récupération du matériel génétique du bison des bois de ce parc essentielle à tout programme d’éradication de la maladie. La récupération du matériel génétique peut être effectuée soit en récupérant des animaux vivants, soit en adaptant au bison des techniques de reproduction développées pour les bovins. Il faudra mener des recherches supplémentaires pour adapter des techniques comme la fécondation in vitro, la superovulation et la cryoconservation de spermatozoïdes et d’ovules, et pour valider les protocoles de récupération d’animaux vivants (protocole de récupération du bison des bois). L’objectif serait de récupérer entre 95 % et 100 % de la diversité génétique actuellement présente dans la métapopulation du parc Wood Buffalo, en récupérant au moins 200 bêtes. On évalue que la population de la région pourrait retrouver son niveau actuel (environ 4 500 bêtes) en 10 ans.

Dans le cadre de l’élaboration d’un protocole d’éradication de la tuberculose bovine et de la brucellose, les participants à l’atelier ont également examiné d’autres maladies, comme la paratuberculose (*Mycobacterium avium paratuberculosis* (MAP)). Ils ont établi que les autres maladies ne constituaient pas une menace pour les bisons en liberté. La MAP en particulier ne semble pas causer de maladie clinique chez les bisons en liberté et ne semble pas devoir être un problème dans l’avenir étant donné sa présence chez plusieurs espèces. Il faut éviter l’introduction de la diarrhée virale des bovins (DVB) chez les nouveaux bisons.

L’une des préoccupations associées au scénario de dépeuplement-repeuplement est la perte possible de comportements appris permettant la survie dans la région du parc Wood Buffalo. On s’est entendu sur le fait que toute perte de comportement appris serait temporaire et que les comportements pourraient être réappris rapidement. De plus, les comportements innés importants seraient préservés grâce à la récupération du matériel génétique.

Le coût total du repeuplement et de la récupération du matériel génétique est estimé à 14 millions de dollars.

Les répercussions écologiques du dépeuplement et du repeuplement ont d’abord été discutées dans le contexte d’un modèle de simulation élaboré à l’université d’Ottawa (Patrick Boily et Scott Findlay). Ce modèle permet de prédire, dans le temps et dans l’espace, les changements qui toucheraient la densité et la distribution des populations de bisons, de caribous, d’orignaux et de loups pendant la période de dépeuplement/repeuplement, ainsi que les changements qui pourraient toucher des habitats spécifiques à cause de la disparition d’un herbivore important. Comme le modèle est encore en développement, le groupe de discussion s’est concentré sur la définition de paramètres pour le modèle et d’un ensemble de répercussions négatives possibles du dépeuplement/repeuplement du bison. Ces résultats non modélisés comprennent les effets potentiels sur les espèces en péril, les changements structurels à long terme touchant les communautés végétales, les changements à long terme touchant la population ou le matériel génétique de populations spécifiques de vertébrés, et la perte potentielle d'espèces d'invertébrés associées aux bisons. La plupart des participants étaient d'avis qu'une période de dépeuplement de dix ans associée à une période de repeuplement à peu près équivalente serait peu susceptible d'entraîner des réactions en chaîne indésirables qui pourraient causer la disparition locale d'espèces. On a suggéré des modifications au modèle, notamment l'utilisation d'un concept expérimental de comparaison avant-après (BACI) pour tester les prédictions du modèle et déterminer les effets de l'opération de dépeuplement/repeuplement sur les interactions des espèces et des habitats. On a également recommandé l'utilisation, pour le modèle, d'une cellule de base de 25 km^2, de quatre intervalles de temps saisonniers et d'un horizon total de 20 ans. On a convenu que le modèle devrait porter principalement sur une évaluation de la probabilité de résultats « indésirables » et « intolérables », identifiés comme : 1) la réduction de l'abondance des espèces en péril; 2) les changements à plus long terme dans d'importantes communautés végétales, en particulier la perte ou la réduction brusque de la qualité de l'habitat du pré à cause de l'introduction d'espèces exotiques; 3) l'intrusion de bisons après le repeuplement; 4) des densités de loups très faibles ou très élevées; 5) une faible abondance d'orignaux ou de castors; 6) des augmentations substantielles de populations de charognards, notamment d'ours noirs et de corbeaux; et 7) la disparition des invertébrés obligatoires associés au bison. Il faut conserver au modèle assez de souplesse pour tenir compte des nouveaux scénarios qui pourraient survenir pendant la phase de mise en œuvre, et intégrer la gestion adaptative comme composante importante de la stratégie de mise en œuvre. Le coût total de conception d'un nouveau modèle, d'un programme de surveillance de la végétation et de l'écosystème et des mesures d'atténuation a été estimé à environ 13,5 millions de dollars.

En conclusion, les participants à l'atelier se sont entendus sur la faisabilité technique de l'éradication des maladies par le biais du scénario de dépeuplement/repeuplement discuté et présenté, à condition que les ressources, le financement et l'infrastructure de gestion nécessaires à la réalisation d'un programme de 20 ans soient disponibles. On s'est également entendu sur le fait que la Stratégie nationale sur les maladies des espèces sauvages approuvée par les ministres responsables des espèces sauvages en octobre 2005 devrait servir de cadre de travail pour arriver à résoudre le problème des maladies du bison dans le Nord du Canada.

Agenda for Bison Diseases Technical Workshop

Room CW410 (Centre Wing) of the Biological Sciences Building, University of Alberta
October 28-29, 2005

Background and Justification: Bovine brucellosis and tuberculosis were most likely introduced along with 6,673 plains bison, which were translocated to Wood Buffalo National Park (WBNP) between 1925 and 1928 from Wainwright Buffalo Park by the Government of Canada. This is now one of the last remaining wildlife reservoirs of these two diseases in Canada, which has declared its cattle herds free of both diseases after a decades-long eradication program. In addition, recovery of the wood bison, an endangered species in Canada, over the last twenty years has resulted in the re-establishment of several disease-free herds surrounding WBNP, which are now threatened with becoming infected by these two diseases. In 1988, the Interagency Bison Disease Task Force compiled a report that recommended that a Federal Environmental Assessment and Review Process be undertaken to make recommendations on resolving the diseased bison issue. This panel, after numerous public hearings concluded that "…eradication of the existing bison population is the only method of eliminating the risk of transmission of bovine brucellosis and tuberculosis from bison in and around Wood Buffalo National Park to domestic cattle, wood bison and humans" and further recommended that "…all free-ranging bison now living in Wood Buffalo National Park and surrounding areas be removed and replaced by disease-free wood bison". This workshop will bring together scientific and technical experts to discuss the feasibility of undertaking the FEARO Panel Report recommendations with the overall goal of determining whether or not such a course of action would be technically feasible, and the ecological impacts are understood.

Objective: To explore the ecological implications and technical feasibility of eradicating bovine TB and brucellosis through depopulation within and around Wood Buffalo National Park followed by replacement with disease-free wood bison to eliminate the risk of transmission of these diseases to domestic cattle, wood bison and humans as recommended in the 1990 Report of the Environmental Assessment Panel on Northern Diseased Bison (Federal Environmental Assessment Review Office Panel Report #35, 1990).

Scope of discussion: The workshop will strictly be focused on scientific aspects surrounding the feasibility of a depopulation/repopulation scenario for bison in and around Wood Buffalo National Park. *It will not discuss socio-political aspects of such a scenario and discussion of this topic is not to be considered de facto approval of this option by Parks Canada, Environment Canada or any other participant. The workshop will not address the question of whether or not depopulation/repopulation is a desirable or preferred option.* Parks Canada Agency and Environment Canada wish to explore the technical elements of this option that was the primary recommendation of the 1990 FEARO panel report so that all involved in future discussions have a similar understanding of what is meant by it.

Main Discussion Points for 3 Breakout Groups:

Breakout Group 1 - Depopulation – a detailed discussion on the options to carry out depopulation including timeframe, feasible methods, and probability of success using FEARO panel recommendations as a starting point.
Breakout Group 2 - Repopulation and genetic salvage – methods available and feasibility matrix of instituting various techniques, including minimum numbers of bison required.
Breakout Group 3 - Ecological implications of depopulation/repopulation – determine potential impacts and mitigations for major species affected under different management options (bison, moose, wolves, caribou, vegetation communities)

Workshop Agenda

Friday, October 28 (Day 1):

8:00 am – 8:30 am	Continental breakfast meet & greet
8:30 am – 8:50 am	Introductions and overview of the workshop- Stephen Woodley, Parks Canada
8:50 am - 9:10 am	Historical overview of the bison issue – Hal Reynolds, Canadian Wildlife Service
9:10 am – 9:30 am	Overview of Bison Research & Containment program – Damien Joly, USA
9:30 am – 9:50 am	Current management and population update – Stuart McMillan, Parks Canada
9:50 am – 10:20 am	Lessons learned from TB eradication in the Northern Territory – Kel Small, Australia
10:20 am – 10:40 am	Break
10:40 am – 11:00 am	Depopulation lessons – what works, what doesn't – Jim Hone, New Zealand
11:00 am – 11:30 am	Introduction to Breakout Group 1 – Depopulation – Gary Wobeser, CCWHC
11:30 am – 12:00 am	Introduction to Breakout Group 2 – Repopulation/genetic salvage – Todd Shury, Parks Canada
12:00 am – 12:30 pm	Open discussion on organization of workshop
12:30 pm – 1:15 pm	Lunch break
1:15 pm – 1:45 pm	Introduction to Breakout Group 3 – Modelling ecological impacts – Scott Findlay, Univ. of Ottawa
1:45 pm – 3:00 pm	Breakout groups: 1. Depopulation (Gary Wobeser/ Ray Poulin), 2. Repopulation/genetic salvage (Todd Shury/ Ken Kingdon), 3. Ecological implications of depopulation/repopulation (Scott Findlay/John Waithaka) coffee in breakout sessions
4:00 pm – 5:00 pm	Plenary session to summarize & focus discussion – group discussion of results to date

Saturday, October 29 (Day 2):

8:00 – 8:30	Continental breakfast
8:30 – 9:00	Question & Answer period from previous discussion
9:00 – 10:30	Breakout group discussions (cont.)
10:30 – 11:00	Break
11:30 – 12:30	Plenary review
12:30 – 1:30	Lunch
1:30 – 3:00	Plenary review and open discussion
3:00 – 3:00	Break
3:30 – 5:00	Summary & Wrap-up – where do we go from here? - Stephen Woodley

Description and Questions for the Breakout Groups

Breakout Group 1 – Depopulation – Gary Wobeser/Ray Poulin

This group aimed to develop a plausible scenario or scenarios for depopulating wood bison in the area of northern Alberta and the southwest NWT with the aim of eradicating bovine TB and brucellosis. There are 5-7 thousand animals in this area, mainly within Wood Buffalo National Park. Any depopulation scenario must include provisions for genetic salvage. Breakout Group 1 should focus on answering the following:

How would the depopulation be done? Including pattern and methods.
What area would have to be depopulated?
What percentage of the population would have to be killed to ensure success?
How long would the depopulation process take?
What measures would be used determine depopulation had indeed occurred? How long should the region be kept bison free?
What would be the likelihood of successfully eradicating Tb and brucellosis under different scenarios? (Not considering repopulation risks)
What outstanding scientific questions would have to be resolved prior to depopulation? During depopulation? i.e. current distribution of the diseases? Potential reservoirs outside bison?
What test(s) would be used to assure a herd is TB and brucellosis-free? How many years of testing?
What would be your estimate of the costs of various scenarios?

Breakout Group 2 – Repopulation and genetic salvage - Todd Shury/Ken Kingdon

This group aimed to develop a plausible scenario or scenarios for repopulating wood bison in the area of northern Alberta and the southwest NWT, following a program of depopulation to eradicate Bovine TB and brucellosis. The goal would be to re-establish viable, TB and brucellosis-free wood bison populations with at least as much genetic diversity as the original population. Note that genetic salvage techniques will need to be considered at both the depopulation and repopulation stages. Breakout Group 2 should focus on answering the following:

How would the repopulation be done? Including pattern and methods.
How would repopulation/genetic salvage occur? How would you determine if repopulation/genetic salvage has been successful in that you actually got the desired range of alleles?
If repopulation/genetic salvage were done in vitro, where would surrogate cows come from, and how would offspring be handled and transported?
How long would the repopulation process take to get back to present-day population levels?
What would be the likelihood of repopulation/genetic salvage and subsequent rearing successfully eradicate bovine Tb and brucellosis under different scenarios?
What outstanding scientific questions would have to be resolved prior to repopulation? During repopulation?
Are there other diseases (i.e. Johne's disease, BVD) that should be considered during repopulation?
Are there implications for loss of learned behaviours of wild bison if repopulation occurs from individuals from semi-tame or ranched herds?
What would be your estimate of the costs of the various scenarios?

Breakout Group 3 – Ecological implications of depopulation and repopulation - Scott Findlay/John Waithaka

This group primarily aimed to explore a model to estimate the ecological impacts of depopulating, then repopulating, wood bison in the area of northern Alberta and the southwest NWT, centred on Wood Buffalo National Park. The model was developed by Drs. Scott Findlay and Patrick Boily at the University of Ottawa under contract from Parks Canada and the Little Red River/Tall Cree First Nation. The workshop also posed two additional questions on possible behaviour implications for wolves and bison that are not part of the model. Breakout Group 3 should focus on exploring the following:

Would any of the modelled populations become locally extinct? Would populations be so low as to cause loss of genetic diversity? Would there be irreversible changes in vegetation community structure?
Does the current model provide an adequate and realistic structure for examining ecosystem impacts, bearing in mind that the objective is to guide the analysis of different depopulation/repopulation scenarios. If not, how ought it to be modified?
What are the appropriate spatial and temporal scales over which the dynamics of identified valued ecosystem components (caribou, wolves etc.) should be simulated?
How might any adverse impacts be mitigated?
What is the current state of data that can be used to define model "initial" conditions. These data generally should take the form of

estimates of the current spatial distribution of the major model components.
What "external" drivers, that are likely to be relevant over the spatial and temporal scales considered in (2), should be included? Note that there is no point in including external drivers for which no (or very little) information exists on their spatiotemporal distribution.
The model is designed to generate estimates of risk for various valued ecosystem components under different depopulation/repopulation strategies. These represent model predictions, ones that in principle at least might be tested during a depopulation/repopulation exercise. Should depopulation/repopulation occur, what is the experimental design that would provide the strongest test of model predictions?
What ecosystem variables should be monitored during repopulation?
Are their implications for loss of learned behaviours of wolf packs that specialize on bison prey if depopulation occurs?

Workshop Participants with workshop assignments

	Depopulation	**Repopulation/Genetic Salvage**	**Ecological Modelling**
	Matt Besko	Norm Cool	Dale Armstrong
	Ed Coulthard	Gerald Hauer	Patrick Boily
	Brett Elkin	Ken Kingdon[1]	Mark Boyce
	Jim Hone	Maria Koller-Jones	Mark Bradley
	Ray Poulin[1]	Ted Leighton	Scott Findlay*
	Hal Reynolds	John Nishi	Graham Hickling
	Helen Schwantje	Margo Pybus	Richard Leonard
	Kel Small	Todd Shury*	Stuart Macmillan
	Stacey Tessaro	Margaret Wild	John Waithaka[1]
	Gary Wobeser*	Greg Wilson	John Wilmshurst
	Stephen Woodley		
Total	11	10	10

[1] Recorder for Workshop
* Workshop Leader

List of Workshop participants

Name	Title	Affiliation
Dale Armstrong	Biotechnology & Innovation Policy Member	Agriculture, Food & Rural Development, Gov't of Alberta
Matt Besko	Species At Risk Biologist	Sustainable Resource Development, Gov't of Alberta
Patrick Boily	Post-doctoral fellow	Institute of the Environment, University of Ottawa
Mark Boyce	Professor	Biological Sciences, University of Alberta
Mark Bradley	Conservation Biologist	Jasper National Park, Parks Canada Agency
Norm Cool	Conservation Biologist	Elk Island National Park, Parks Canada Agency
Ed Coulthard	Manager of Resource Conservation	Wood Buffalo National Park, Parks Canada Agency
Brett Elkin	Wildlife Veterinarian	Environment & Natural Resources, Gov't of the Northwest Territories
Scott Findlay[1]	Director	Institute of the Environment, University of Ottawa
Gerald Hauer	Assistant Provincial Veterinarian	Agriculture, Food & Rural Development, Gov't of Alberta
Graham Hickling	Research Associate	University of Tennessee
Jim Hone	Associate Professor	Environmental and Heritage Sciences, University of Canberra
Damien Joly[2]	Wildlife Epidemiologist	Field Veterinary Program, Wildlife Conservation Society
Ken Kingdon	Bovine TB coordinator	Riding Mountain National Park, Parks Canada Agency
Maria Koller-Jones	Senior Staff Veterinarian	Canadian Food Inspection Agency
Richard Leonard	Manager of Resource Conservation	Winnipeg Service Centre, Parks Canada Agency
Ted Leighton	Executive Director	Canadian Cooperative Wildlife Health Centre
Stuart Macmillan	Conservation Biologist	Wood Buffalo National Park, Parks Canada Agency
John Nishi	Bison Ecologist	Environment & Natural Resources, Gov't of the Northwest Territories
Ray Poulin	Post-doctoral fellow	Canadian Wildlife Service, Environment Canada
Margo Pybus	Wildlife Disease Specialist	Sustainable Resource Development, Gov't of Alberta
Hal Reynolds	Wildlife Biologist	Canadian Wildlife Service, Environment Canada
Helen Schwantje	Wildlife Veterinarian	Biodiversity Branch, Gov't of British Columbia
Todd Shury[1]	Wildlife Health Specialist/Veterinarian	Ecological Integrity Branch, Parks Canada Agency
Kel Small	Regional Veterinary Officer	Northern Territory Government, Australia
Stacey Tessaro	Manager of Virology & Quality Assurance	Canadian Food Inspection Agency
John Waithaka	Ecological Integrity Specialist	Ecological Integrity Branch, Parks Canada Agency
Margaret Wild	Wildlife Veterinarian	US National Parks Service
John Wilmshurst	Grasslands Ecologist	Winnipeg Service Centre, Parks Canada Agency
Greg Wilson	Geneticist/Lecturer	University of Alberta
Gary Wobeser[1]	Professor	Dept. of Veterinary Pathology, Western College of Veterinary Medicine
Stephen Woodley	Chief Scientist	Ecological Integrity Branch, Parks Canada Agency

[1] Workshop Leader
[2] Presented data, but did not participate in workshop

Total of 32 participants

Proceedings

Summary of Breakout Group 1 - Depopulation

Gary Wobeser/Ray Poulin

The program goal is to completely eliminate bovine tuberculosis (TB) and bovine brucellosis in free-ranging wood bison in the Wood Buffalo National Park (WBNP) area; to maintain a maximum amount of genetic diversity and restore the free-ranging population to at least its current size and distribution.

How would the depopulation be done?

We considered the possibility of depopulating in a progressive manner, whereby bison would be removed from one area, the area would be isolated with fences and then depopulation would begin in the next area. This method was considered because it could allow for the simultaneous repopulation of isolated areas with disease-free bison while the depopulation of other areas continued.

This method was considered very undesirable because of the significant risk it posed in having disease-free bison contaminated by infected bison nearby. The risk of contaminating a disease-free herd was considered proportional to its proximity to infected bison. Even within the confines of a fence the risk was considered too great because of the risk of fence failure (for a variety of reasons). We therefore concluded that the only means to assure that tuberculosis and brucellosis is eradicated from within the WBNP area is to completely depopulate the area of bison, allow for a bison-free period and begin repopulating from herds outside the area. The efforts and resources that would need to be allocated to this entire project would just be too high to accept any risk of failure.

The lessons learned from methodologies used for the water buffalo depopulation project in Northern Territories, Australia indicated some initially inefficiency, but the process became more efficient as personnel gained experience. It was suggested that the initial stages of any wood bison depopulation effort should start at a modest pace to allow personnel time to gain experience and address subtle methodological nuances.

Using “Judas”[1] animals was considered to be a useful method to help find small herds or individual animals. This process involves affixing long-lived radio-transmitters on free-ranging bison. Tagged animals will tend to seek out the company of other bison, thus divulging the location of animals that need to be removed from the population. This method is expected to be particularly useful when the bison population has been reduced to low levels. Based on the experiences from the water buffalo depopulation project in Northern Territories, Australia, it was recommended that radio-transmitters be put on “Judas” animals in the initial phases of the depopulation exercise. It was also suggested that young bulls tended to be the best candidates

[1] Animals which are marked with radio-collars and used to locate and remove remaining uncollared animals.

for being successful “Judas” animals; however, the social behaviour of cows does make them worth consideration for this method.

Corral-traps were considered to be the most efficient method for removing a large number of animals in the initial stages of depopulation but may also be efficient throughout much of the project. Bison would be drawn into these traps by placing the corrals in areas where the bison are known to congregate and by placing food bait within the corral. It was suggested that portable corrals would be more useful than permanent corrals for this purpose. It was also noted that bison would quickly learn to avoid corral-traps through experience. It would likely be most efficient to target the largest herds early in the depopulation process.

Shooting from both the ground and from the air will be an essential component to depopulation. This method will be particularly useful for removing small herds or isolated individuals and will likely be the only efficient method in the final stages of depopulation, when bison densities are low.

Several other methods should be considered for assisting in the complete depopulation of the area.

Encourage participation from local communities.

Consider the option of providing sliding-scale bounties to local hunters. (as bison densities decrease, the amount of the bounty increases).

Consider the option of setting up hunting camps for local hunters.

Hazing may be considered an option for driving bison herds to corral-traps or areas more suited for shooting.

When given the choice, it is more important to remove cows rather than bulls.

Work should be concentrated during winter, when it is easier to locate bison from the air, it is easier to bait them into traps, it is more difficult for the bison to run, and it prevents the addition of some spring calves into the population (i.e. killing a cow is sometimes the equivalent of killing a cow and a calf).

Consideration should be given to high-tech methods for locating animals (e.g. satellite or infrared images).

The entire process of depopulation will benefit from the simultaneous and coordinated use of all available methods.

In conjunction with the methods of how to depopulate the area, we addressed the question of what to do with the carcasses? We agreed that every attempt should be made to remove all carcasses from the landscape because of the risks associated with disease transmission to secondary hosts (e.g. wolves, deer) and because of the unknown consequences that may emanate through the ecosystem (e.g. increase in scavenger or predator populations). We encourage use of the carcasses (e.g. meat) where possible, thus consideration should be given to the need for meat inspectors, portable abattoirs and the possibility of establishing processing facilities. Mobile facilities of the type used for musk-ox harvest on Banks Island may be suitable in some situations.

We anticipate that a large number of bison can be removed with the use of corrals, thus simplifying the disposal of the carcasses. Those carcasses resulting from shooting should be removed or properly destroyed, where possible. We acknowledge that some isolated carcasses would have to be left in place because of logistic constraints but deemed that these instances would not increase the risk of disease transmission or ecosystem disruption.

This depopulation scenario complies with the proposed Interim Measures Agreement between the governments of Alberta, the Northwest Territories and Parks Canada Agency.

What area would have to be depopulated?

In order to eradicate tuberculosis and brucellosis in wood bison, all areas in and around WBNP that support diseased or diseased-exposed bison (i.e., where the disease status is unknown) would have to be depopulated. Areas desired to be exempt from depopulation (e.g. Hay-Zama and Mackenzie Bison Sanctuary) must undergo a thorough test of their populations to establish their disease-free status.

What percentage of the population would have to be killed to ensure success?

As discussed above, the only way to ensure complete elimination of tuberculosis and brucellosis is to depopulation 100% of the wood bison population.

How long would the depopulation process take?

First and foremost, we agreed that the depopulation of the entire population of wood bison in the WBNP area is technically feasible. The amount of time it would take to depopulate the area is somewhat difficult to predict because of the uncertainty of many factors (e.g. expertise of personnel, willingness of public, political fortitude, landowner cooperation, and unpredictable events). However, funding is likely the greatest limiting factor in determining the length of time this process would take. Under ideal circumstances, we estimate that depopulation of the entire area could take place within a decade. Based on data and simulations provided by Jim Hone (see appendix I), we anticipate the vast majority of the population could be removed in the first three years but that it would take another four to seven years to remove the last remnants of the population.

What measures would be used to determine depopulation had indeed occurred?

Currently, WBNP conducts aerial grid-surveys every second year. As we approach complete depopulation status, these aerial grid-surveys should be expanded to cover the entire depopulation area (including periphery of area) and should be conducted on an annual basis. These surveys will also be used to identify the locations of remaining bison. Fixed-wing aircraft will significantly reduce the costs of surveying compared to helicopters.
Consideration should also be given to erecting wing-fences to restrict bison movements through traditional corridors and thus allowing for regular (weekly/bi-weekly) concentrated surveys in these areas. Surveys of corridors can use snow tracking but should also consider methods such as trip wires or automated cameras.

Careful data should be kept in order to monitor the catch per unit effort; this will help determine when the population is approaching zero. Consideration should be given to establishing a "bison-hotline" whereby bison sightings can be reported by the public. Consideration should be given to using high-tech surveillance (e.g. satellite) to search for remaining animals. "Judas" animals should continue to be utilized at the later stages of depopulation to help locate the last remaining animals. Consider using several "Judas" animals after the population is considered depopulated, if the several "Judas" animals cannot locate any bison over time, the population could be considered at or near zero.

How long should the region be kept bison free?

The area should be kept free of bison for a length of time greater than the length of time the disease-causing bacteria can persist in the environment. *Mycobacterium bovis* and *Brucella abortus* can likely persist in the environment for about six months. Once the area is considered free of bison, we suggest that the areas be kept free of bison for an additional two years. During these two years, rigorous surveys should continue to determine the maintenance of the bison-free status. If bison are discovered in the area during the bison-free period, they should be removed and tested for disease. If they are positive for tuberculosis or brucellosis, the two-year clock should be reset. If a disease-negative bison were discovered on the periphery of the area, it would likely be an immigrant from a disease-free herd and should not force a resetting of the two-year time period. A non-diseased bison discovered in the core of the area may initiate a resetting of the two-year time period depending on the likelihood that the animal was an immigrant from a non-infected population in the area.

What would be the likelihood of successfully eradicating TB and Brucellosis under different scenarios?

Complete depopulation of the area following by a bison-free period will ensure complete elimination of tuberculosis and brucellosis from the wood bison around WBNP. The likelihood of failing to eradicating these diseases is proportional to the number of bison that escape the depopulation process (i.e. because of the contagiousness of these diseases, if a single infected bison survives the depopulation process, it could potentially infect the population that repopulates the area).

What outstanding scientific questions would have to be resolved prior to or during the depopulation?

The Hay-Zama and Mackenzie Bison Sanctuary populations must be tested for the presence of tuberculosis and brucellosis. If they are positive for either disease, they must be included in the depopulation.

White-tailed deer and mule deer can be infected with tuberculosis and brucellosis and their populations have been increasing in the WBNP area. It is believed that these species are spillover hosts for these diseases and that they would probably not pass the disease on to bison. However, consideration should be given to removing and testing all white-tailed and mule deer encountered during the bison depopulation activities. The goal of this exercise would be to determine the risk that these deer may pose on bison used to repopulate the area.

What test(s) would be used to assure a herd is TB and Brucellosis-free?

Post-mortem tests are the only effective techniques to determine if a bison has tuberculosis. Where possible, a suite of tests should be employed. As well as cultures for all killed animals (including representative tissues apparently without lesions), testing for brucellosis should include four serology tests (Buffered Plate Agglutination Test [BPAT], Complement Fixation [CF] Test, cELISA, Florescence Polarization Assay [FPA]) and testing for tuberculosis should include a histology workup, Acid Fast Staining (Z-N stain) and diagnostic tests (Gamma-interferon test, (experimental) Florescence Polarization Assay and possibly Lymphocyte Stimulation Tests[LST]).

Following the precautionary principle, all animals from untested populations (e.g. farms) will be considered infected until it is proven that the herd is free of disease.

A standard formula will be used to determine the probability of detecting a particular prevalence (x %) of the disease(s) in a population within a particular (y %) confidence interval.

What would be your estimate of the costs of various scenarios?

Speculation on the costs of implementing the depopulation scenario(s) above are intended to provide an order of magnitude of the costs. A more accurate estimate of costs would require a detailed inventory of items and expenditures.

We estimate the full depopulation scenario (outlined above) may cost between $35 and $50 million over 10 years. This estimate was based on figures outlined in the Agriculture Canada (1989) document. These costs include the cost of building permanent corrals, building access roads, building meat processing facilities, salvaging meat, and preserving a maximum amount of genetic diversity.

We estimate that these costs could be cut in half if we salvaged the meat from the corral-traps (removing the largest and “easiest” herds over two to three years) and then shoot and leave the rest.

We estimate that the costs could be reduced by 90% if we did not use corrals and we did not remove carcasses. However, this scenario does not account for the increase in costs associated with dealing with public relations and the possible costs/risks associated with compromising the ecological integrity of the ecosystem (thousands of carcasses across the landscape is bound to have cascading effects through the system).

Summary of Breakout Group 2 - Repopulation and Genetic Salvage

Todd Shury/Ken Kingdon

How would the repopulation be done?

Repopulation would only occur with the following points taken into account:

> There is certainty beyond any reasonable doubt that there are: a) no diseased bison, and b) no residual disease risk in the ecosystem based on appropriate and ongoing testing of bison in surrounding populations (e.g. Hay-Zama, Wentzel-Wabasca and Mackenzie Bison Sanctuary herds).
>
> The bison herd repopulation will be starting with no bison in the area that was formerly considered to have diseased bison (based on ongoing testing to ensure disease freedom at an appropriate level of testing).
>
> That only wood bison types with origins from the WBNP metapopulation (not plains bison types) will be reintroduced, and animals will be selected based on genotypic make-up, rather than phenotypic traits.

Repopulation would be achieved by introducing at least 1,000 animals over three to four years, once depopulation is completed. The bison in the reintroduction population would be built-up at the same time as depopulation was occurring, through the use of off-site breeding stations. It is suggested that a large number of bison be acquired from the TB and brucellosis-free bison of Elk Island National Park (EINP), as well as from the more genetically diverse herd in Wood Buffalo National Park (WBNP). Other source herds of disease-free bison, other than EINP, should be evaluated by the Canadian Food Inspection Agency (CFIA) for inclusion in the reintroduction program (qualitative risk assessment will be necessary to establish the value of these other herds as potential sources of bison). Examples of these would include the existing Syncrude and Waterhen herds.

The release will be conducted as a soft release of young animals (calves and yearlings) from fenced compounds in and around WBNP. Introduction would likely be in February or March. As stated, a total of 1,000 animals would be released into the Park, with 500 in first release, and an additional 500 animals in the years immediately after. Soft release could mean remaining in a large captive corral anywhere from 6 months to 3 years.

The breeding stations could be set up on existing bison ranches in areas away from WBNP.

How would genetic salvage occur?

There needs to be significant emphasis on retaining existing genetic diversity in the WBNP bison. Breeding records should be kept and breeding management done so that genetic diversity is conserved between generations. The genetic makeup of the animals would be recorded after every breeding event, ensuring that genetic diversity is maximized. EINP founder animals would represent approximately 200 animals. WBNP founder animals would also represent at least 200 animals, as Wood Buffalo animals are the most genetically diverse wood bison population.

If repopulation/genetic salvage were done in vitro, where would surrogate cows come from, and how would offspring be handled and transported?

To determine the effectiveness of advanced reproductive technology (ART) in bison, further study will need to be done, perhaps by modifying the University of Saskatchewan bison project proposal. *In vitro* fertilization is of interest, in particular, the recovery of ova and semen from collection of ovaries/testes post mortem from WBNP animals. It is expected that any salvaged WBNP bison will be screened for both TB and brucellosis by Florescence Polarization Assay in the field (immediately). Research on bison semen collection has already been done, but more work is needed on storage and cryopreservation.

It is expected that wood? bison from EINP would act as surrogate cows. Offspring handling and transportation would be through normal industry methods.

How would you determine if repopulation/genetic salvage has been successful in that you actually get the desired range of alleles?

Breeding should be monitored at each stage. Diversity should be maintained through a managed breeding program, and by ensuring that genetic salvage of diseased bison occurs. The goal would be to capture between 95% and 100% of the genetic diversity currently present within the WBNP metapopulation. Genetic testing of bison in WBNP, EINP, and Mackenzie Bison Sanctuary to date has indicated that if cattle genes are present in these populations, it is below a level of introgression of approximately 1.5% (Pers. Comm., Greg Wilson based on Halbert et al. (2005)). This is similar to the level of testing that has been done in Yellowstone National Park to ensure that their plains bison are free from cattle genes (Halbert et al. 2005).

How long would the repopulation process take to get back to present-day population levels?

We recommend a total of 1,000 animals be released into the WBNP area – 500 in the first year release, with an additional 500 animals in the subsequent year(s). A minimum of 1,000 animals should be introduced and monitoring of populations would follow. It is expected that the population would approach 4,000 animals in less than 10 years.

What would be the likelihood of repopulation/genetic salvage and subsequent rearing successfully eradicating bovine TB and brucellosis under the different scenarios?

Based on the experience gained from the Hook Lake Wood Bison Recovery Project, there was general consensus that genetic salvage from the diseased herds in WBNP is possible. New protocols, dubbed the wood bison TB salvage protocols, could be established to ensure that genetic salvage is not done at the cost of establishing a disease-free population (and vice versa). Protocols, using live births, would be expected to include orphaning calves at birth, and determining the TB status of the dams immediately post partum. Any calf whose dam is found to have gross visible lesions would be deemed to be at risk of TB or brucellosis and would be slaughtered as well. Calves would not be considered 'clean' until confirmatory culture results were confirmed negative. Calves would be tested regularly for both genetics and for disease. This technique was successfully used to develop the current herd of wood bison in EINP in the late 1960's from diseased animals from WBNP. Some validation of this salvage technique (i.e. wood bison TB salvage protocol) would be required prior to it being implemented, to ensure that it would be successful.

If *in vitro* procedures are chosen for genetic salvage, then the risk of disease transfer is extremely low. Further research on assisted reproductive techniques that have been developed for cattle and other species is required for wood bison.

What outstanding scientific questions would have to be resolved prior to repopulation? During repopulation?

Research questions:

Is disease present in bison herds adjacent to WBNP? For example, wood bison in the herds at Hay-Zama and in the Mackenzie Bison Sanctuary should be tested.
Are there areas of disease on the landscape that could act as a source of re-infection once depopulation had occurred? That is, are there reservoir hosts that could remain infected with bovine TB or brucellosis that could serve to re-infect reintroduced wood bison?

What learned behaviours will be lost and can we measure changes in behaviour?

We need to test the effectiveness of the wood bison TB salvage protocols, over 3 to 5 years. These protocols involve salvaging wood bison from diseased individuals using lessons learned from the Hook Lake Wood Bison Recovery Project (see above for description of this protocol).

Adapt existing cattle breeding technology to bison (both in vitro and in vivo) and develop techniques that could be used to salvage genes from diseased bison (ART – advanced reproductive technology).

Are there other diseases (e.g. *Mycobacterium avium paratuberculosis* (MAP), BVD) that should be considered during repopulation?

Embryo transfer recipient cows should be disease-free, including other diseases such as *Mycobacterium avium paratuberculosis* (MAP a.k.a Johne's disease) and Bovine Viral Diarrhea (BVD). Bison cows from EINP could be a source of disease-free animals.

There was a lot of discussion about the importance of MAP, as well as BVD in bison. General consensus is that BVD should be avoided, if possible. However, there has been PCR positive results on testing for MAP in many wild herds, based on fecal samples. MAP appears to be widespread in northern Canada (Woodbury 2005), thus it may be of little use to re-introduce MAP-free animals. MAP is not currently a reportable disease under the Health of Animals Act and Regulations in Canada. This disease does not seem to be a concern for free-ranging bison from a clinical point of view and it, most likely, will not be a future issue for disease eradication in domestic stock due to its ubiquitous nature in many free-ranging species.

Are there implications for loss of learned behaviours of wild bison if repopulation occurs from individuals from semi-tame or ranched herds?

There was general consensus that there could? be a loss of learned behaviors. However, there was also recognition that there is little to be done on this issue, as it will be necessary to remove the entire population to attain disease-free status. There was also consensus that any lost behaviors could be re-learned quickly or innate behaviors would be conserved through genetic salvage.

What would be your estimate of the costs of the various scenarios?

Total cost of the repopulation/genetic salvage was grossly estimated to be **$12.5 to $14.5 Million**.

This can be broken down:

Construction of "breeding stations" - $ 3 to 5 million dollars

Operating costs of breeding stations - $1 million/year, for 6 years (total $6 million)

Lab costs for TB Testing - $ 600,000

Genetic testing of bison throughout process - $190,000

Live testing of release animals - $200,000

Post Surveillance monitoring - $500,000

Advanced Reproductive Technology (ART) – technology development - $500,000
actual salvage - $1 million

Decommissioning the soft release holding pens - $500,000

Literature Cited

Halbert, N. D., T. J. Ward, R. D. Schnabel, J. F. Taylor, and J. N. Derr. 2005. *Conservation genomics: disequilibrium mapping of domestic cattle chromosomal segments in North American bison populations*. Molecular Ecology, **14**: 2343-2362.

Woodbury, M. 2005. *Workshop on Mycobacterium avium subsp. paratuberculosis in North American Bison (Bison bison): Proceedings and workshop report*. British Columbia Ministry of Environment. 51 pp.

Summary of Breakout Group 3 - Ecological Implications of Depopulation and Repopulation

Scott Findlay/John Waithaka

The aim of Breakout Group 3 was to evaluate the potential ecological consequences of bison depopulation and subsequent repopulation in and around Wood Buffalo National Park (WBNP), Canada's largest national park that covers 44,807 km^2. The discussion focused on a simulation model that is being developed by Scott Findlay and Patrick Boily of the University of Ottawa under a contract with Parks Canada and the Little Red River/Tall Cree First Nation.

The model is designed to evaluate the potential ecological impacts of bison depopulation and repopulation on selected valued ecosystem components (known as assessment endpoints in the language of risk modelling and referring to animal species and habitats in the park that could benefit or be harmed by bison management). The model focuses on the temporal and spatial changes in density and distribution of bison, caribou, moose and wolves during the depopulation-repopulation period, and the possible changes in specific habitats due to the removal of a key herbivore from the ecosystem.

Key criteria for the model include: (1) spatial explicitness; (2) flexibility, i.e. ability to accommodate a variety of species and habitats; (3) the capacity to accommodate large uncertainties, including those associated with the spatial distribution and interaction of model components on the landscape, particularly since the data required to parameterize functional relationships between model components will be scarce or absent; and, (4) the ability to predict the risk for different depopulation/repopulation scenarios.

The Breakout Group 3 participants examined the components of the initial model and the range of outcomes it was designed to predict. A series of questions set prior to the meeting (see Agenda on p. 11) to stimulate debate enabled participants to look beyond the estimated outcomes in the initial model. The participants assessed whether the most valued ecosystem components likely to be impacted on by the depopulation/repopulation exercise were incorporated in the model, identified specific undesirable scenarios that the model should be able to address, and suggested changes that would reduce the level of uncertainty in the model predictions. The results were presented to the plenary for input from everyone at the meeting.

It was clear from the outset that there would be no clear answers to any of the questions posed. Firstly, there are no simple ways of predicting the spatial and temporal dynamics within ecosystems. Secondly, the model was not ready and hence the participants did not have this important resource to evaluating the potential risks associated with the wider range of possible depopulation/repopulation scenarios, and finally, additional expertise would be required to evaluate specific outcomes.

Following the initial evaluation of the model and the questions posed for the workshop, the group decided to change the direction of the discussions. Rather than provide information for the model that would be anecdotal, the group identified a set of possible undesirable outcomes of the bison depopulation/repopulation scenario, and developed a list of questions that should be answered by the model. These questions were:

1. What would be the effects on species at risk?

2. What would be the long-term structural changes in vegetation communities?

3. What would be the long-term population and/or genetic and/or range change in specified vertebrate populations?

4. What would be the potential for loss of bison-associated invertebrate species?

As a result, some initial components of the model were omitted and new ones were added. It was recommended that the modelling approach be redesigned to address the proposed changes. The revised modelling exercise should provide a structure that both takes explicit account of these uncertainties, as well as explore their consequences to the risks associated with alternate depopulation/repopulation scenarios. How this model should be built was not discussed in depth.

Project Period

Based on experiences from similar projects carried out elsewhere, the estimated depopulation phase of the experiment is 6-10 years, with another 10 or so years required during the repopulation phase to bring up a disease-free population to its current level. The model has three major stages: the pre-depopulation phase; the depopulation phase, and the repopulation and post-repopulation phase. These periods should be used in the model simulations, and the final model will be available in May 2006.

ANSWERS TO THE QUESTION POSED

The following are responses to the initial questions posed. The answers are not conclusive and will require re-assessment by experts once model development is completed.

Would any of the modeled populations become locally extinct? Would populations be so low as to cause loss of genetic diversity?

The model is designed to estimate the risk of local (i.e. park-wide) extinction under different depopulation/repopulation scenarios. However, workshop participants were of the view that with respect to the species and habitat types which the model will explicitly address (see below), the risk of local extinction is very low under virtually all "reasonable" depopulation/repopulation scenarios. Historically, bison numbers have fluctuated dramatically, with no observable catastrophic responses of the target species of wolves, beaver, moose or caribou. In the historical primary range of the wood bison that stretched across boreal forest regions of Alaska, the Yukon Territory, the Northwest Territories, and northern Alberta and British Columbia, the population was estimated at 168,000 animals in 1800, but declined almost to extinction during the 19th century. By 1900, the range of wood bison had declined to approximately the area currently designated as WBNP, where only about 250 animals remained. In all areas where the bison has been exterminated within the last 100 years, there are no known extinctions that have been associated with the absence of the species. It was widely felt that a ten-year depopulation period and an approximately ten-year repopulation period is unlikely to result in undesirable ecosystem cascades that would result in local extinction of species. Moreover, three of the target species (wolf, beaver, and moose) are reasonably common both inside and outside the park, which further reduces the likelihood of (long-term) local extinction.

Local extinction risk is necessarily greater for species with small population sizes in WBNP. Of particular concern is the possibility that woodland caribou, a species listed as threatened under Schedule 1 of the Species At Risk Act (SARA), would suffer increased mortality through wolf predation. Some concerns were also raised about potential increased extinction risks to the Whooping Crane, an endangered species that breeds only in WBNP. It was recommended that the Whooping Crane be included in the model.

Would there be irreversible changes in vegetation community structure?

The model will investigate changes in vegetation structure associated with bison removal, with a focus on meadow, grassland, and fen habitats. Again, however, workshop participants considered the risk of irreversible and substantial (at the park level) changes in these habitats to be low. Bison are currently found throughout WBNP in several free-ranging herds whose distribution changes both seasonally and annually in response to changing environmental conditions. While there is some anecdotal evidence to suggest that on small spatial scales they may influence successional dynamics, (i.e. in wallows), there is little evidence that bison have been a driver of habitat dynamics in WBNP over the past few decades; indeed, given low historical densities, such effects would be unexpected. However, there are some confounding interactions with shrub densities in some areas related to changing bison densities and flooding, but whose direct cause and effect would be impossible to establish.

Even where localized habitat dynamics may be affected by the removal of bison, the proposed short period over which depopulation and subsequent repopulation will proceed is unlikely to have long-lasting chronic effects on habitat distribution within WBNP.

Does the current model provide an adequate and realistic structure for examining ecosystem impacts?

The initial model included 10 dynamic endpoints: four species (bison, wolf, moose and woodland caribou) and six habitat types (deciduous forest, spruce forest, pine forest, grassland, fen and willow/sedge).

Revisions to the model

It was agreed that the model should be concerned primarily with an assessment of the likelihood of "undesirable" and "intolerable" outcomes, i.e. outcomes that would substantially degrade the current value of WBNP. Such outcomes were identified as: (1) reductions in abundance of species at risk; (2) longer-term changes in important vegetation communities, especially loss or dramatic decline in meadow habitat quality from exotic weeds; (3) post-repopulation bison irruptions; (4) very low or very high wolf densities; (5) low moose or beaver abundance; (6) substantial increases in scavenger populations, particularly bear and ravens; and, (6) loss of obligate bison-associated invertebrates.

In light of the discussion of undesirable outcomes, the workshop participants recommended that the set of species be expanded to include (a) Whooping Crane, (b) scavengers (bears, ravens) and (c) white-tailed deer.

The model would be designed to incorporate scenarios that would detect:

The decline in a species at risk, particularly the Whooping Crane and woodland caribou.

Long-term structural changes in vegetation communities, particularly the loss of meadows and expansion of area under weeds.

Long-term population changes in vertebrate populations, including;

post repopulation bison irruption.

very low or high wolf densities.

low moose and/or beaver densities.

substantial increases in scavenger populations represented by ravens and bear.

Loss of bison-associated invertebrate species.

Participants were unanimous that over the time-scales (20 years) that will be simulated, the pine, spruce and deciduous habitats were unlikely to change and were removed from the model.

What are the appropriate spatial and temporal scales over which the dynamics of identified valued ecosystem components (caribou, wolves etc.) should be simulated?

As currently structured, the model divides WBNP into a set of square grid cells. (A grid cell is a space within which the dynamics related to a modeled ecosystem component takes place). The size of the grid cell can be adjusted, but the preliminary simulations are made over a 200 X 200 grid (40,000 cells, i.e. each cell approximately 1.5 km^2). Temporally the model simulates seasonal dynamics (i.e. 4 time steps per year) with a total time horizon of twenty years (6-10 year depopulation phase, 1-14 year repopulation phase).

Workshop participants concluded that for the purposes of exploring different depopulation/repopulation scenarios and their associated risks, a grid-size of 25 km^2 was appropriate. At this spatial scale, only bison and wolves were considered likely to move between grid cells in a single time step.

Animal densities in each grid cell were estimated from the bison survey conducted in 1999. Additional information is available from surveys conducted in 2000, 2001, 2002, 2004 and 2005.

The strength of interactions between components in each grid cell is estimated using a 9-point scale ranging between –1 and +1, where –1 is a strong negative interaction, 0 is no interaction, and +1 is a strong positive interaction. A species can act at any location within an interactive matrix varying across geographic and seasonal scales.

Habitat-type densities are based on a proportional scale, where a habitat with a density of 0.2 represents 20% of the vegetation in the grid cell. However, the spatial variations within the grid cells are ignored, as they are unlikely to introduce serious errors given the size of the cells.

This discussion highlighted the need to adopt an approach other than a matrix model in which all habitat types and all species are considered in combination, as many of the resultant grid cells would be empty or have no useful information. A more efficient approach would be to consider interactions between species and habitats one by one.

How might any adverse impacts be mitigated?

The model will produce general risk estimates for undesirable or intolerable outcomes for each question, given a range of depopulation/repopulation scenarios. Mitigation strategies will depend on the nature, cause(s), extent, and potential consequences of adverse impacts. Results from modelling will form the basis for the development of criteria for choosing the most plausible risk management options. These options include differentiating scenarios that will require adaptive management from those that may call for relatively radical and intrusive management, including predator management, and/or artificial habitat management (e.g. prescribed burning, simulated grazing).

What is the current state of data that can be used to define model "initial" conditions? These data generally should take the form of estimates of the current spatial distribution of the major model components.

As a baseline, the model uses the 1999 bison survey data, which provides good information on densities and spatial distribution that covers WBNP. There are also good spatial data for preceding periods which can be used for model calibration for the "before depopulation" period.

The survey reports (for specified end-points) for which data are available for model development and calibration are listed below.

<u>Bison</u>:

Bergeson, D. 1999. Bison Total Count Survey. 1999. Unpublished Parks Canada report.

Mitchell, J., C. Kaeser and M. Bradley. 2000. Wood Buffalo National Park 1999 Ungulate Reconnaissance Survey: Field Report. Unpublished Parks Canada report.

Bergeson, D. 2000. Bison Segregation Survey, Peace-Athabasca Delta, 2000. Unpublished Parks Canada report.

Bradley, M., A. Handel, and P. Sargent. 2002. Wood Buffalo National Park Bison Survey, March 2002. Unpublished Parks Canada report.

Bradley, M. 2002. Wood Buffalo National Park Bison Segregation Counts, 2001 and 2002. Unpublished Parks Canada report.

Bradley, M. 2003. Wood Buffalo National Park Bison Survey, March 2003. 2003. Unpublished Parks Canada report.

Bradley, M. and C. Zimmer. 2004. Wood Buffalo National Park Bison Segregation Counts, 2004. 2004. Unpublished Parks Canada report.

Zimmer, C. and S. Macmillan. 2005. Wood Buffalo National Park Bison Survey, March 2005. Unpublished Parks Canada report. (in prep.).

Macmillan, S., C. Zimmer, and D. Campbell. 2005 Wood Buffalo National Park Bison Segregation Counts, 2005. Unpublished Parks Canada report. (in prep.).

Moose:

Gunn, L. and M. Bradley. 2001. Wood Buffalo National Park Moose Census, Ft. Smith Study Area., November 2000. Unpublished Parks Canada report.

Mitchell, J., P. Sargent and M. Bradley. 2001. Wood Buffalo National Park Moose Census, Garden River Study Area. December 2001. Unpublished Parks Canada report.

Sargent, P., A. Handel and M. Bradley. 2002. Wood Buffalo National Park Moose Census, Ft. Chipeweyan Study Area. 2002. Unpublished Parks Canada report.

Wolf:

Systematic data on wolves is lacking, but information on predation rates and densities are available for other regions, which can be extrapolated to WBNP.

Vegetation communities:

The model uses the vegetation habitat mapping for the greater WBNP ecosystem produced in 2003 (Jensen, 2003)

What "external" drivers, that are likely to be relevant over the spatial and temporal scales considered in the model, should be included? Note that there is no point in including external drivers for which no (or very little) information exists on their spatiotemporal distribution.

Changes to the modeled species and habitats will vary in time and space. Some of these changes will be self induced, or ecological (population growth, predation, herbivory) and some will be driven by the environment (fire, weather, flooding, etc.). The model(s) will only consider environmental factors that change at approximately the same pace as the ecological changes, and snow depth was identified as significant. Environmental influences that occur over long periods of time, such as climate change will be considered to be constant in the model.

The model is designed to generate estimates of risk for various valued ecosystem components under different depopulation/repopulation strategies [These represent model predictions, ones that in principle at least might be tested during a depopulation/repopulation exercise]. Should depopulation/repopulation occur, what is the experimental design that would provide the strongest test of model predictions?

Participants recommended that a BACI (Before/After – Control/Impact) experimental design be employed to test model predictions and to determine how species and habitats will interact in the face of the depopulation/repopulation "project". This design was recommended because it allows the project to distinguish between events that would have happened regardless of the manipulation from those that are clearly responding to the manipulation. It will involve careful selection of replicate matched ("paired") control and impact sites, the former being areas where bison are not removed, the latter where they are, with monitoring of measurement endpoints being done at multiple replicate sites within each category before depopulation occurs, during the depopulation period, and during/after the repopulation period.

The outstanding experimental issue in implementing a BACI design is the designation of control sites. This issue was considered beyond the scope of the workshop, but participants were unanimous that the appropriate designation of control and impact sites will require expert judgment as well as insights gained from the model. Nevertheless, workshop participants were unanimous that pre- and post-intervention monitoring in the context of a powerful experimental design was crucial to the successful implementation of the depopulation/repopulation strategy.

What ecosystem variables should be monitored during repopulation?

As noted above, the effective prosecution requires an appropriate experimental design as well as a carefully selected set of monitoring endpoints. As such, workshop participants suggested that a pre-post monitoring program be implemented including the following endpoints:

Changes in densities and distribution of bison, moose, beaver, and potentially scavenger populations;

Pre-post depopulation wolf densities in 5 regions;

Predator-prey dynamics: changes in densities of alternative prey;

Long-term structural changes in the meadows habitats;

Expansion of area under weeds (non-native vegetation); and,

Trends of some invertebrates that are associated with bison.

A proposal was made to expand the geographical scope of the monitoring program to include the entire ecosystem. It was also proposed that satellite technology could be used to detect animals at low densities.

Are their implications for loss of learned behaviors of wolf packs that specialize on bison prey if depopulation occurs?

Natural life expectancy for wolves in the wild is 5-9 years. Within a period of 10-20 years, there may be two or three generations that may not encounter the bison, hence the learned behavior could be lost. However, the participants were unanimous that even if bison predation behaviors were lost, it was likely that these behaviors would be reacquired (during the repopulation phase), as they have in other situations. This was not considered an important impact.

What costs would be associated with the project?

The costs associated with ecological impacts of the project were discussed under the following categories:

Model redesigning for post-experimental monitoring and for adaptive management;

Surveys of bison, caribou, wolf, and moose;

Mitigation costs such a predator management, prescribed burns/simulated grazing to maintain/enhance desired habitat dynamics, and, potentially, to mitigate the risks of exotic plant species invasion; and,

Vegetation survey – transects and satellite imaging.

Cost estimates for survey and monitoring activities for specific activities follow:

Caribou: $1.5 million

Wolf: $2.5 million

Moose: $ 5 million

Bison: $3 million

Vegetation: Satellite maps $800 K

Encroachment by exotics $640

Invertebrates associated with bison $150 K

Total: $13,590,000

Conclusions:

The risk of the WBNP ecosystem experiencing irreversible or catastrophic changes as a result of the removal of the bison for about 6-10 years was low. Species at risk could be the exception to this conclusion, as it would not take much of a change to result in a catastrophe.

The draft model should be revised in light of recommendations outlined above.

It is important that the model retain sufficient flexibility to accommodate novel scenarios that may arise during implementation.

Adaptive management is to be an important component of the implementation strategy.

Literature Cited:

Jensen, O. 2003. Assessing suitable and critical habitat for Wood Bison (*Bison bison athabascae*) using Geographic Information Systems (GIS) and remote sensing. M.Sc. Thesis, Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton.

Summary of Plenary Discussions

Initial results of the Breakout Group discussions were presented on Friday afternoon Oct. 28th and the main points that were discussed are summarized below:

- Likelihood of success of disease eradication is very high if 100% of diseased animals can be depopulated.
- The area that would have to be depopulated may be difficult to define especially on the southern boundary, but would be established based on testing of animals through post mortem and culture of tissues for *M. bovis* and *B. abortus*.
- How long would the depopulated area have to remain free of bison? Longer than the organism (*M. bovis*) can reasonably survive in the environment (6 months to 2 years).
- Depopulation is feasible based on the six criteria defined in Bomford and O'Brien (1995).
- There may be some benefit in doing a "trial run" and learning the best ways to depopulate through adaptive management prior to a full depopulation effort as was employed in Australia.
- How long would depopulation take? At least a decade, but it would depend on how much money was available.
- Main method of depopulation would involve baiting and corralling of bison in core areas.
- Automated corrals with self-closing doors could be used.
- Hazing with wing fences would work, but there are negative historical connotations associated with this method.
- Individual shooting (both ground and air based) could be used in some areas with incentives for local hunters, a technique that was successfully used in Australia.
- "Judas" animals should be used early in the process.
- All these techniques should be used concurrently.
- The plan developed by Agriculture Canada in the early 1990's (Agriculture Canada 1989) could be used as a starting point and overall guide.
- How would you know if you had 100% depopulation? This could be accomplished through maintaining a grid system that currently exists for annual population surveys. You could also monitor known movement corridors for tracks as a method of surveillance.

- Two years after the last bison was removed should be the required period of time with no bison existing on the landscape in the depopulation zone.

- Can the possibility of other disease reservoirs be eliminated? Not entirely, but the possibility of other reservoirs is probably quite remote with the exception of white-tailed deer and mule deer which have recently invaded the park ecosystem from the south.

- The loss of learned behaviors would most likely result from depopulation and repopulation, but this was not believed to be a significant impact as most behaviors would be relearned quite quickly.

- The temporary loss of herbivory through removal of a keystone herbivore from the ecosystem for a period of time (up to 10 years or more) was NOT felt to be an important ecological impact over the long term.

Two plenary sessions were held on Saturday October 28th and the main points that were discussed are summarized below:

- Large numbers of carcasses left on the landscape could potentially lead to an irruption in the raven population which could result in increased Whooping Crane mortality. This is something that could be included in an environmental assessment.

- Environmental assessment prior to any plan would have to be comprehensive and should include possibility of loss of bison-associated invertebrates.

- Carcass disposal considerations may not be a major concern as the bulk of the bison removal would be done through corral trapping where carcasses could be managed and properly disposed or salvaged.

- Depopulation could not be effectively completed if it were done as a progressive "moving wave" of depopulation with repopulation occurring simultaneously. The risk of re-infection would be too great considering the resources and effort expended on depopulation.

- It may be necessary to reduce predation pressure on reintroduced bison for a short period of time while populations are rebuilding.

- It is important to point out that there are many methods of conducting depopulation, some of which may cost substantially less. There may be other types of costs (i.e. social costs) associated with the economically lower costs though.

- Determination of success following repopulation may be difficult to define as the bison population in and around WBNP has fluctuated fairly dramatically historically between

500 and 12,000 animals. Population growth rate parameters may be a better measure of success rather than absolute population number.

- Location and timing of bison removal would need to be worked out in a detailed fashion prior to depopulation.

- Depopulation of the diseased bison in and around WBNP followed by repopulation with healthy, wood bison was unanimously agreed to be technically and logistically feasible as discussed at this workshop provided that adequate resources and public support are available.

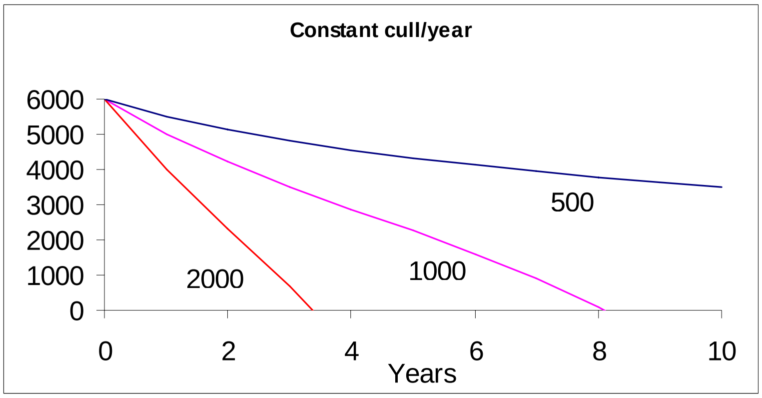
Literature Cited

Agriculture Canada. 1989. *Agriculture Canada's Submission to the Northern Diseased Bison Assessment Panel*, 17 November 1989: 96 pp.

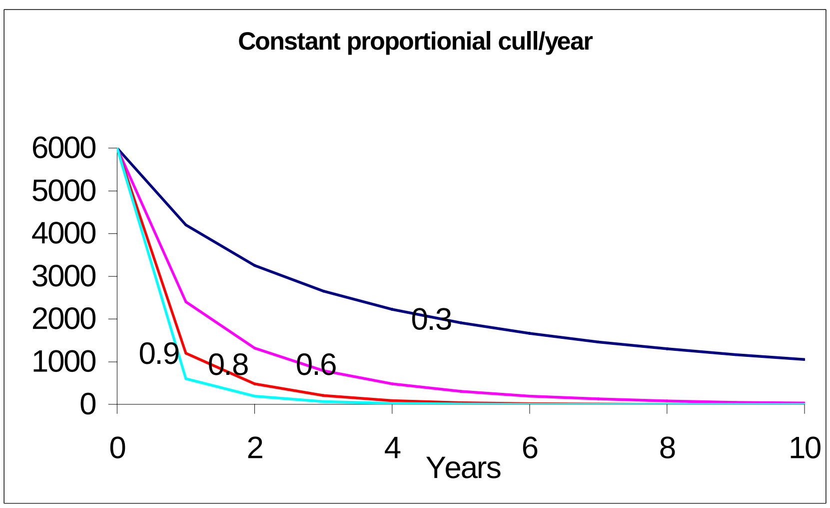
Bomford, M. and P. O'Brien. 1995. *Eradication or control for vertebrate pests?* Wildlife Society Bulletin 23: 249-255.

Appendix I – Graphs developed by Jim Hone for Depopulation breakout group

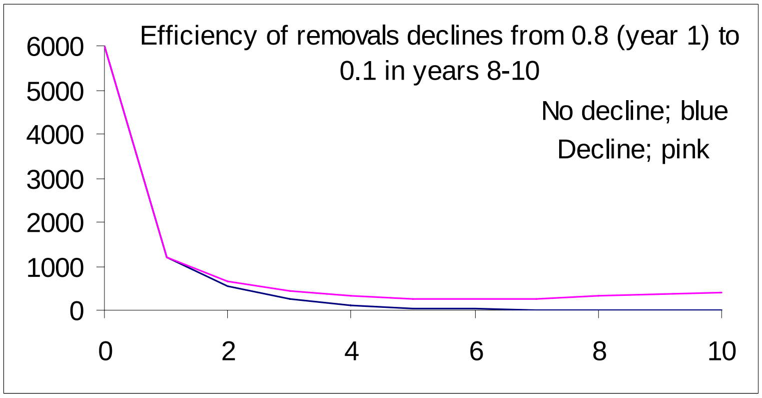
The original assumptions for the following graphs assume: 1) logistic growth of a discrete population, 2) initial population size of 6000 bison, 3) no additional mortality (besides culling), and 4) an intrinsic population growth rate (r_m) of 0.25. Relative to theta logistic population growth, here it is assumed that theta equals 1.0 (hence logistic growth).



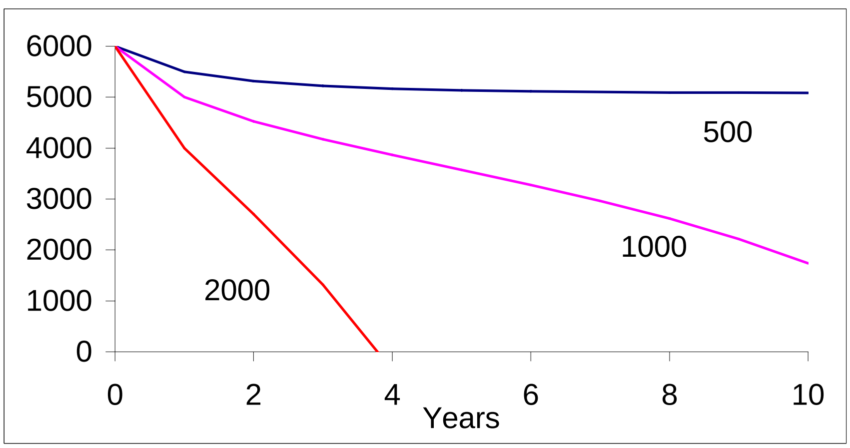
The above graph presents the effect of three different constant cull rates (animals culled per year). For example, if culling successfully removes 2000 bison per year, it will take approximately three years to depopulate while it would take eight years if 1000 bison per year were removed. It is assumed that theta equals 1.0.



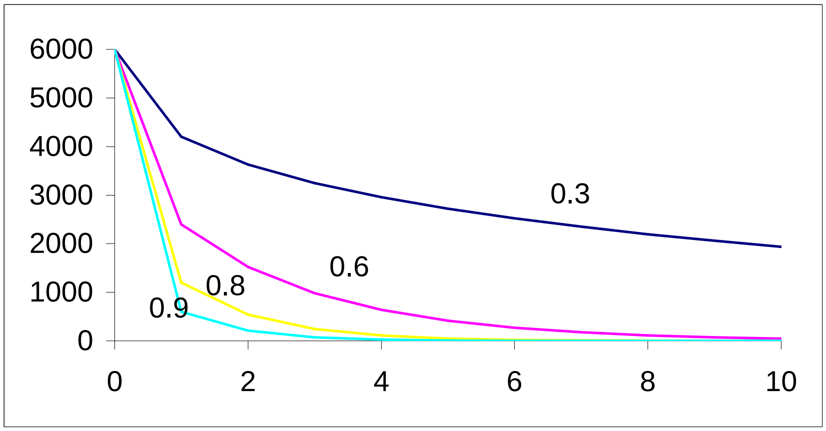
The above graph presents the effect of removing a proportion of the bison population annually ranging from 0.3 (30%) to 0.9 (90%), rather than an absolute number. It is assumed that theta equals 1.0.



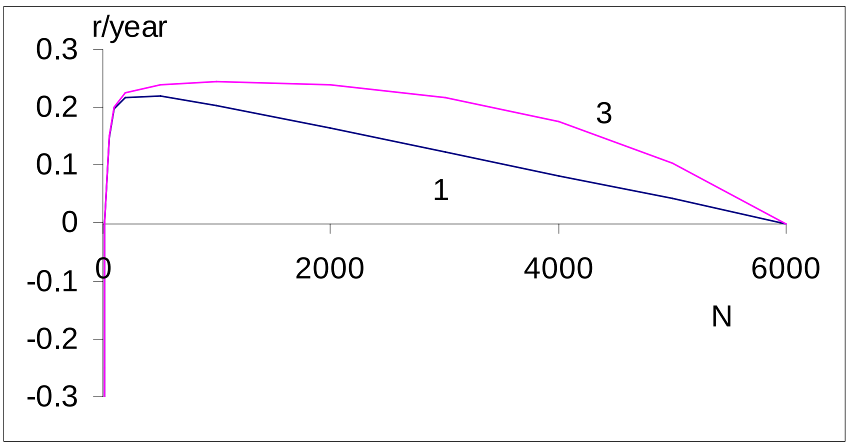
The above graph demonstrates the effect of declining efficiency of removal over the period of depopulation. It assumes that the efficiency of removal declines in a linear manner from 0.8 (80% of bison population removed) in the first year to 0.1 (10% of bison population removed) in years 8 to 10. It is assumed that theta equals 3.0 so density-dependence occurs at higher density than in previous graphs.



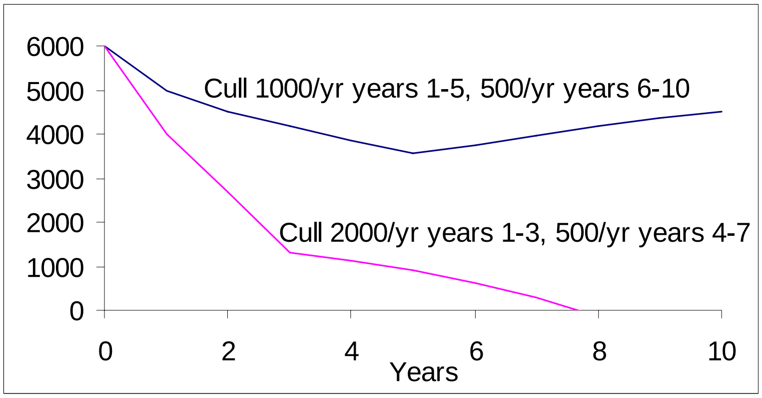
The above graph demonstrates the effect of compensatory increases in survival and reproduction as bison density decreases (density dependence) with constant culling rates. It is assumed that theta equals 3.0. Culling has less effect on bison abundance when theta equals 3.0 than when theta equals 1.0 (shown in graph 1).



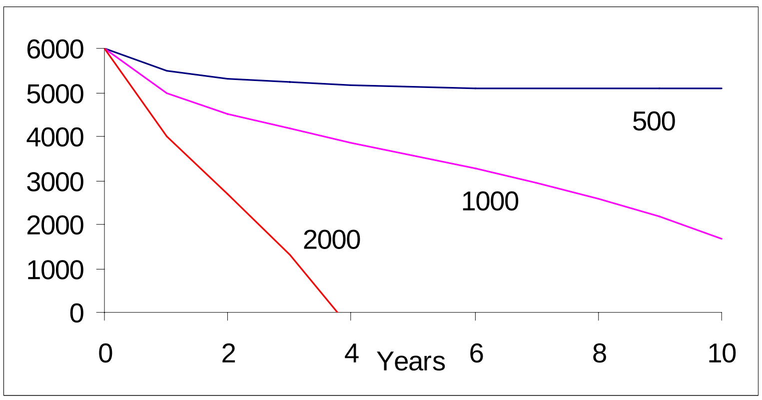
The above graph demonstrates the effect of compensatory increases in survival and reproduction as bison density decreases (density dependence) with proportional culling rates. Culling has less effect on bison abundance when theta equals 3.0 than when theta equals 1.0 (shown in graph 2).



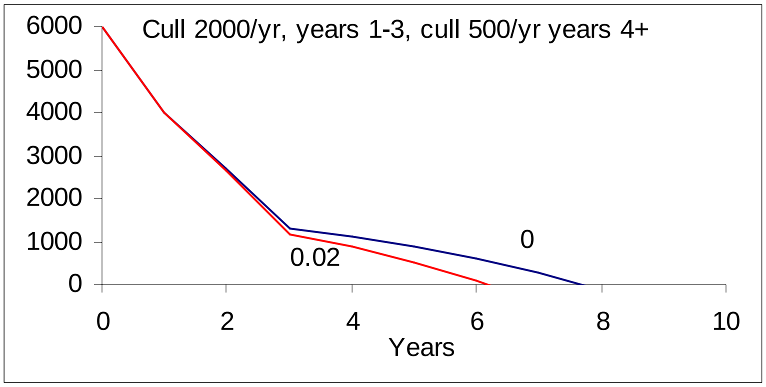
This graph demonstrates the Allee effect on population growth rate (*r*) for different values of theta (1 or 3). The blue and pink lines assume that there are two equilibria; a higher capacity (K_1) at 6,000 and a lower capacity (K_2) at 20. Below 20 bison abundance decreases ($r < 0$).



The above graph simulates the effect of variable culling over time as a result of budgetary losses or changes in efficiency of removals over time. The blue line assumes 1,000 bison culled per year in years 1 to 5 and only 500 removed per year in years 6 to 10. The pink line assumes 2,000 bison culled per year in years 1 to 3 and 500 per year in years 4 to 7. The graph assumes theta equals 3.0.



The above graph simulates theta logistic growth (theta equals 3.0) at three different cull rates with the addition of an Allee effect. The Allee effect is : "…a phenomenon in biology named after W. C. Allee, who first wrote extensively on it. It describes a positive relation between population density and the per capita growth rate. In other words, for smaller populations, the reproduction and survival of individuals decreases. This effect usually saturates or disappears as populations get larger" (www.wikipedia.org). This essentially simulates increased wolf predation at low bison densities. The two equilibria are 6,000 and 20 bison. The Allee effect has little effect here as only at the highest culling rate (2,000/yr) does abundance get down to the low level at which the Allee effect acts.



The above graph simulates the effect of selective removal of females rather than a random cull. It is assumed that selective removal produces an effect like a decrease in r_m. The blue line assumes r_m is constant (0 change per year) and the red line is what happens if it decreases in a linear manner at a rate of 0.02 per year. This also simulates a decline in habitat quality over time from prime to marginal habitat if bison move as a result of culling activities. This graph makes the following assumptions:

1. Generalized logistic growth; rm=0.25/yr, K=6000, K2=20, theta =3

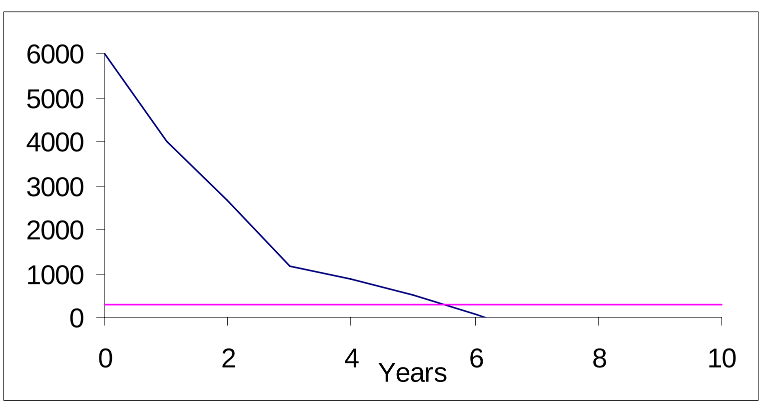
2.Selective removal of females that reduces r_m by 0.02/yr

3. Remove 2000/yr in years 1-3, 500/yr in years 4+

4. Constant environment

5. Remove after breeding season

6. Removals in short time period each year



The above graph repeats the red line (marked 0.02) in the previous graph and compares it with a possible effect of a proportion of the area or bison population not being accessible due to being hidden in heavy cover or some other factor. The pink line is the assumed number of bison (300) not accessible. Hence if some bison are not accessible then culling cannot remove all animals.

Appendix II: Workshop Presentations Friday, October 28th, 2005

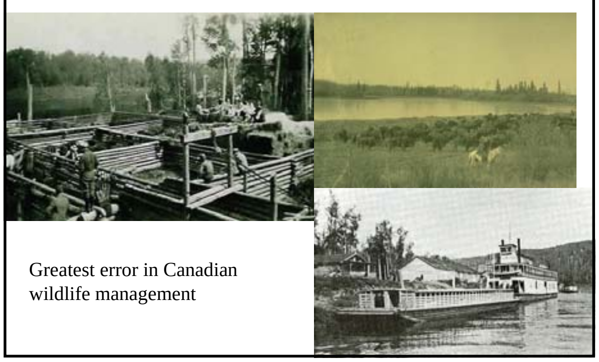
1. Wood Bison, Bovine TB, Brucellosis and You - Stephen Woodley
2. Historical Overview of the Northern Diseased Bison Issue - Hal Reynolds
3. Overview of Bison Research & Containment Program - Damien Joly
4. Wood Buffalo National Park: bison population update - Stuart Macmillan
5. Depopulation for disease control: the northern territory experience - Kel Small
6. Wildlife depopulation: issues and examples - Jim Hone
7. Tuberculosis and brucellosis in bison: depopulation - Gary Wobeser
8. Repopulation and genetic salvage - Todd Shury
9. Ecological modelling - Scott Findlay/ Patrick Boily

Wood Bison, Bovine TB, Brucellosis and You

A Very Short HISTORY

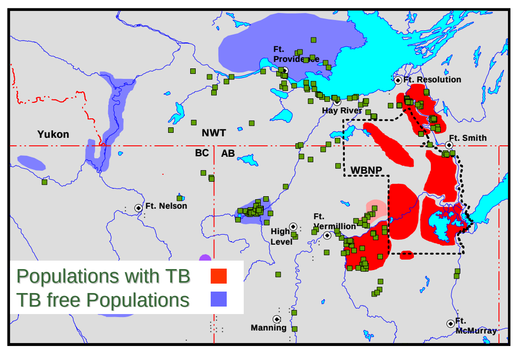
1890 Bison reduced to remnant in North America
1903 Pablo herd – Montana to Wainwright – mixed with cattle
1922 : Wood Buffalo National Park (WBNP)
1924-24 Public outcry over bison culls in Wainwright
1925-28 : Introduction of infected plains bison to WBNP
1963 : Mackenzie Bison Sanctuary established
1975 : Wood Bison Recovery Program begins
1984 : WBNP named a World Heritage Site
1990 : FEARO Panel recommends depopulation & repopulation – public outcry
1992 : Northern Buffalo Management Board Report
1995-00 : Bison Research & Containment Program
2002: US imposes trade restrictions on cattle from Manitoba
2003: SARA in force; Increases in region's livestock and bison

Shipping Bison to Wood Buffalo



Greatest error in Canadian wildlife management

Bison Sightings in Northern Canada



Why We Are Here

- **To provide technical advice to a larger decision making process (National Wildlife Disease Strategy).**
- **Specifically answer three questions:**

1. How would depopulation be accomplished?
2. How would repopulation be accomplished?
3. What would be the ecological consequences?

We are not here to:

- Make decisions about the future of bison
- Answer the question of should bison be depopulated and repopulated to eradicate the disease
- Represent any group, agency or government

How will we work

Short Background papers
Workshop Introductions in plenary
Breakout
- review questions
- discussions recorded

Report to plenary
Breakout
- revisions

Final Plenary
FINAL REPORT – PDF available to all

Information to be Recorded

1. Answers to the questions posed
2. Unknowns
3. Costs – estimates
4. Specific recommendations based on consensus

What area would have to be depopulated? Example

1. Defined by herd or map; estimated number of animals
2. Unknowns – test Hay Zamma minimum 200 animals
3. Costs – test costs for 200 animals @ 1000/animal

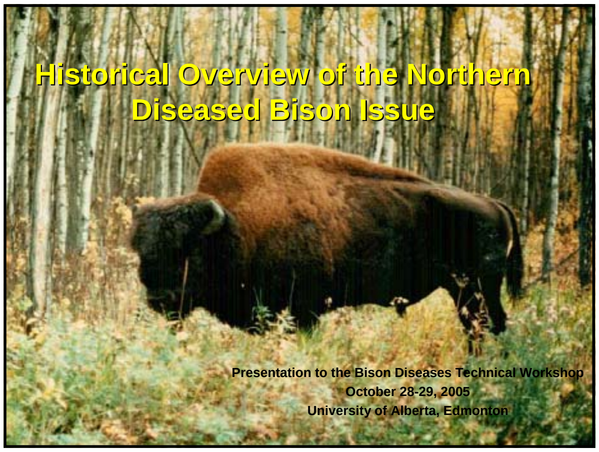
Workshops and Assignments

Depopulation – Gary Wobeser / Ray Poulin

Repopulation and genetic salvage - Todd Shury/ Ken Kingdon

Ecological implications of depopulation and repopulation - Scott Findlay/ John Waithaka

	Depopulation	**Repopulation/Genetic Salvage**	**Ecological Modelling**
	Hal Reynolds	Todd Shury*	Cormack Gates
	Helen Schwantje	Maria Koller-Jones	Richard Leonard
	Gary Wobeser*	Margaret Wild	Scott Findlay*
	Ed Coulthard	John Nishi	Stuart Macmillan
	Stephen Woodley	Norm Cool	Patrick Boily
	Brett Elkin	Greg Wilson	John Wilmshurst
	Stacey Tessaro	Ted Leighton	Graham Hickling
	Matt Besko	Margo Pybus	Mark Bradley
	Ray Poulin[1]	Gerald Hauer	Mark Boyce
	Kel Small	Emily Jenkins	John Waithaka[1]
	Jim Hone	Ken Kingdon[1]	Dale Armstrong
Total	11	11	11

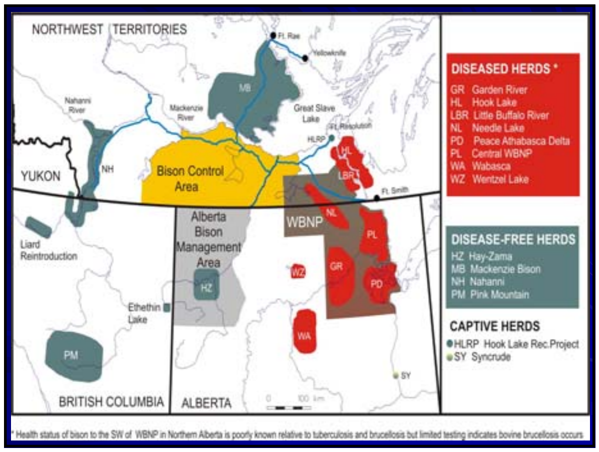


THE ISSUE

- Bison herds in and around Wood Buffalo National Park of Canada are highly infected with bovine tuberculosis (49%) and brucellosis (31%).
- The presence of these diseases pose a serious threat to humans, domestic livestock (cattle and bison), and to the restoration of disease-free wood bison herds in northern Canada.

Why the concern about TB and brucellosis?

- **Both diseases are *zoonoses*, ie they cause human diseases via contact with infected animals or unpasteurized milk.**
- **TB is a primary concern of the World Health Organization.**
- **These diseases affect international trade in livestock.**
- **Bovine brucellosis was eradicated from Canadian livestock in 1989.**
- **Canada's farmed cattle and bison population is virtually TB-free (according to international standards, this means 99.9% of cattle herds are free).**



HISTORY

- 1922 : Wood Buffalo National Park (WBNP) established
- 1925 – 28: Introduction of infected plains bison and hybridization
- 1963 : Mackenzie Bison Sanctuary wood bison herd established
- 1965 : Captive source herd established at Elk Island National Park
- 1975 : National Wood Bison Recovery Program begins
- 1984 : WBNP named a World Heritage Site

DISEASE HISTORY # 1

- TB in Park bison first noted in Fort Chipewyan Mission Diaries in 1937-38
- Bison shot at Fort Smith in 1944 later found to have had TB
- TB confirmed in Park bison in 1947
- Brucellosis confirmed in Park bison in 1956
- Bovine TB and Brucellosis most likely came with the plains bison
- In 1952-53 high incidence of TB noted in Park herds
  - cull recommended to reduce incidence
  - decline of caribou in north led to interest in bison as another meat source
- **Bison Management Program 1954- 1962**
  - to reduce incidence of disease, mainly TB
  - to focus on testing for disease prior to slaughter, however…
  - culling mainly for meat with little selective killing for disease
- Program stopped 1962 because of public criticism and lack of acceptance
  - Public more sensitive to environmental issues and the national park concept

DISEASE HISTORY – # 2

- New focus on disease control in 1962 with Anthrax outbreak at Hook Lake, SRL
- Anthrax appeared in WBNP in 1964
- **1968 Management Proposal for WBNP:**
  - 5 major enclosures (Lake One and Lake Claire – 262 mi²; Hay Camp, Raup Lake, and Hornaday River – 236 mi²)
  - employ test and slaughter of reactors and vaccinate annually
  - after 5 years all bison would be enclosed, 50% pop. destroyed, remaining 4000 animals would be disease-free for TB, Bruc and would be vaccinated for anthrax
  - after 10 years the Park range would be TB, Bruc-free and bison could be freed
- **1968 Management Proposal Rejected:**
  - cost and free-roaming nature lost for world's largest herd
  - perceived local, national, international criticism of large slaughter
  - residents Fort Smith and Fort Resolution opposed removal of a source of food

DISEASE HISTORY – # 3

- WBNP Management Programs 1972 – 1977
- 1972 Management Program developed "to maintain as large a disease-controlled herd as possible"
  - proposed a series of small corrals at strategic locations near migration routes and concentration areas throughout the Park
- In 1975, Program objective modified, "To maintain in a free-roaming state as large a disease-controlled herd as possible within the ecological limits of park resources."
  - based on continued aerial surveys, construction of corrals to increase vaccination rate, and to design and implement a long-term research program
- In 1975 – Technical Committee (Parks/CWS) formed
- Annual roundups were terminated in 1977
  - because of high cost, difficulty in capturing and vaccinating significant numbers, short-term nature of vaccine, harassment stress and mortality, and public criticism

DISEASE HISTORY – # 4

- 1986: Interjurisdictional Steering Committee Established
  - in response to concern about nat'l and internat'l implications of the large disease reservoir of Tb/brucella in WBNP region
  - reps from CPS, Ag Can, GNWT, CWS, Health& Welfare Can, AB Ag & AB FWS
- 1986 : Disease Task Force created by SC
  - to review existing information and evaluate management options
- 1988 : Disease Task Force Report
  - "Evaluation of Brucellosis and Tuberculosis in Bison in Northern Canada"
  - considered 9 Options, but presented 4 in detail (Status Quo, Wood Bison Recovery & Disease Eradication, Fencing WBNP, Confine Disease to WBNP)
  - recommended establishing a Task force of scientific personnel from each agency to provide Managers with guidance on the issue

DISEASE HISTORY – # 5

- 1988: Bison Disease issue referred to an Environmental Assessment Panel:
  - to publicly review and assess possible solutions and their potential impacts
  - to recommend a solution and assess its impacts on environment, resource conservation, people, and the local economy
- 1988/89: Panel identifies key issues and concerns, holds scoping sessions in 9 communities, Yellowknife and Edmonton, commissioned reports from 6 technical experts
- Agriculture Canada accepted role of proponent with a proposal to depopulate
- 1990: Panel conducted public hearings in 5 communities; Fort Smith/Edmonton
- 1990 (August) : EA Panel Report recommends depopulation & repopulation with disease-free wood bison

DISEASE HISTORY – # 6

- 1991 (June): Northern Buffalo Management Board established
  - in response to EARP report and after consultation with stakeholders.
  - to develop a management plan for eradication of bovine tuberculosis and brucellosis in diseased bison in and around WBNP.
  - 19-member board co-chaired by a native representative and DIAND.
- 1992 (December): Northern Buffalo Management Program Report
  - spent $1.2 M.
  - identified significant knowledge gaps to be filled prior to plan development.
  - identified a management strategy for a community-based program to reduce risk of spread of disease, pilot projects to test management options, and collection of traditional and scientific data.
  - requested approval $18 M over 3.5 years.

DISEASE HISTORY – # 7

- 1995 (December): multi-stakeholder Research Advisory Committee (RAC) established under the Bison Research and Containment Program (BRCP)
  - to contain the diseases and to establish a basis for management decision-making grounded in science, traditional knowledge, and consensus
  - budget of $5M over 5-year Research Program
  - funded U of C bison movement corridors study
  - funded the 3-year U of S research project ($1.3M) – 49% test positive for TB; 31% test positive for Br; diseases unlikely to disappear; alter predator-prey relationships
- 2001: RAC and BRCP Final Report
  - recommended 4-year extension to work on 6 additional research topics
  - requested an additional $1.8M
  - the bison disease issue in WBNP is one of the most complex issues facing PCA

DISEASE HISTORY – # 8

- 2002-2005: Increase in WBNP diseased bison from a low of 2200 to 4000+
- 2003: Increases in region's livestock and healthy bison
- Increased population size in WBNP = Increased risk for transmission of diseases
- 2003-05 : Interim Measures Working Group – PCA, AB Ag & SRD, GNWT

  - to establish buffer zones on west side of Park to contain and manage diseases

RISKS : WOOD BISON RECOVERY

- Wood Bison are listed by COSEWIC as "threatened" and are listed on Schedule 1 of Species at Risk Act as a threatened species.
- The greatest single factor limiting range availability and the potential for further recovery of disease-free wood bison in Canada is the existence of diseased bison herds in and around WBNP – WB Recovery Plan (2001).

WHERE DO WE GO FROM HERE?

- There is a need for a:

  Multi-stakeholder collaborative management planning process for detailed evaluation and costing of the depopulation/repopulation and genetic salvage scenario to eradicate disease.
- There is a need to refer this issue:

  As a priority under the mandate of the National Wildlife Disease Strategy.

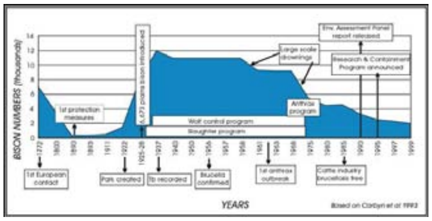
Wood Buffalo National Park

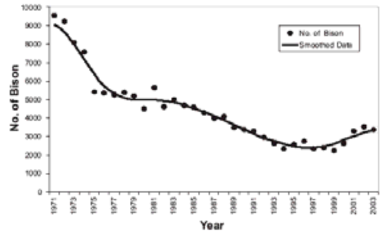
Bison Population Update

Bison Diseases Technical
Workshop, Edmonton, Alberta
October 28-29, 2005

Outline

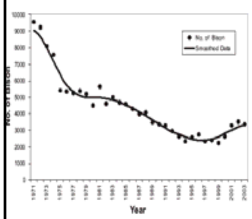
Historical context
Recent trends
2005 Update
Discussion

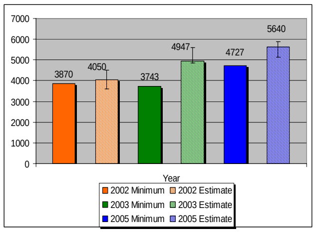


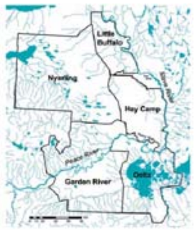


Size of bison population in Wood Buffalo National Park, 1971-2003.

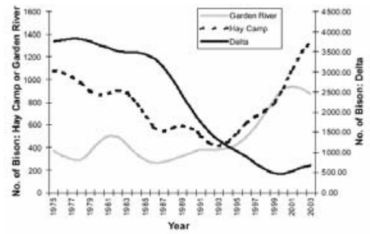
(From: Bradley, M. and J. Wilmshurst. 2005. The fall and rise of bison populations in Wood Buffalo National Park: 1971 to 2003. Can. J. Zool. 83: 1195-1205)



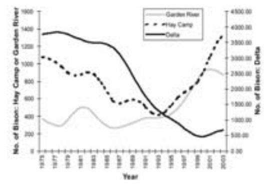




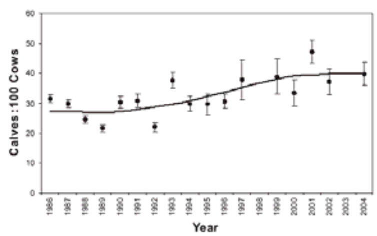
Bison sub-population areas in Wood Buffalo National Park.



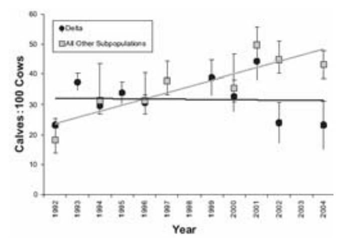
Population sizes for the Delta, Hay Camp and Garden River sub-populations (smoothed data), 1975-2003. (From: Bradley and Wilmshurst, 2005).



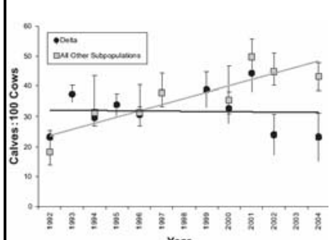
Subpop	2003	2005	Change
Delta	827	1312	+ 485 (59%)
Hay Camp	1383	1755	+ 372 (27%)
Garden River	892	523	- 369 (41%)



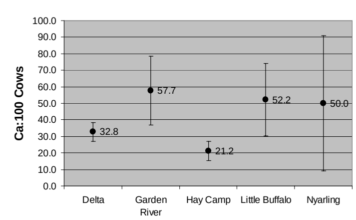
Calf : 100 cow ratio for Wood Buffalo National Park, 1988-2004. (From: Bradley and Wilmshurst, 2005)



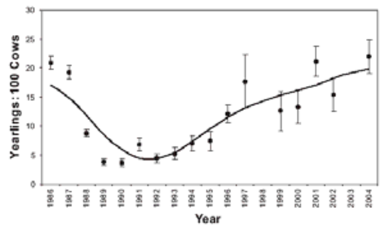
Comparison of calf : 100 cow ratios between the Delta subpopulation and all other WBNP subpopulations (from: Bradley and Wilmshurst, 2005).



2005	Ca: 100 Cow	Change
Total	31.8	-7.89 (20%)
Delta	32.76	+ 9.75 (42%)
Other	30.93	-12.27 (28%)

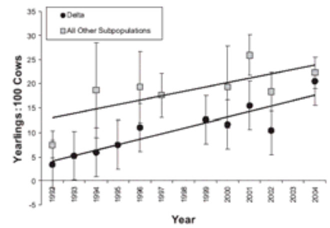


2005 calf : 100 cow ratios by subpopulation, Wood Buffalo National Park.

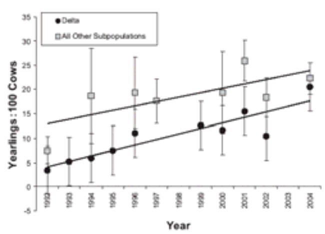


Yearling : 100 cow ratios for Wood Buffalo National Park, 1988-2004.

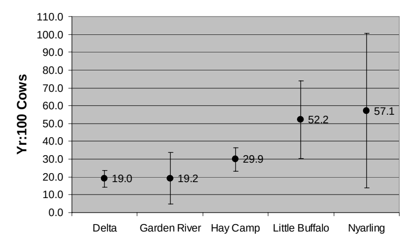
(From: Bradley and Wilmshurst, 2005)



Comparison of yearling : 100 cow ratios between the Delta subpopulation and all other WBNP subpopulations (from: Bradley and Wilmshurst, 2005).



2005	Yr:100 Cow	Change
Overall	25.82	+ 3.85 (17%)
Delta	19	- 1.5 (7%)
Other	32	+ 9.7 (44%)



2005 yearling : 100 cow ratios by subpopulation, Wood Buffalo National Park.

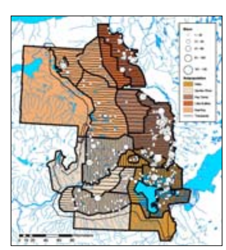
Summary

Overall population growth is continuing, particularly in Delta.

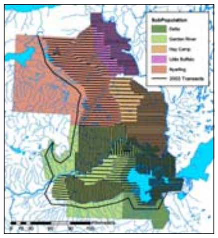
Long-term population trends differ among sub-populations even though disease prevalence is similar. Delta decline before year 2000 appears to have been unique.

Juvenile survival may be an important indicator of population trend.

- juvenile mortality appears to be higher in delta (lower yearling:100 cow ratios). Disease prevalence is lower in Delta; wolf predation is a likely cause of higher juvenile mortality.



Bison observations, 2003 bison survey.



Transects for the 2003 and 2005 surveys.

Overview of the Bison Research and Containment Program

and

Overview of Bison Research by the University of Saskatchewan

Damien O. Joly
Field Veterinary Program
Wildlife Conservation Society

PI: François Messier
Department of Biology
University of Saskatchewan

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Bison Research and Containment Program

- Established in 1995 by the Ministers of Agriculture and Canadian Heritage
- In turn, the Minister of Canadian Heritage appointed the Research Advisory Committee
  - December 2005 – April 2001

Research Advisory Committee

- "Identify, prioritize, and recommend research ..."

Research Advisory Committee

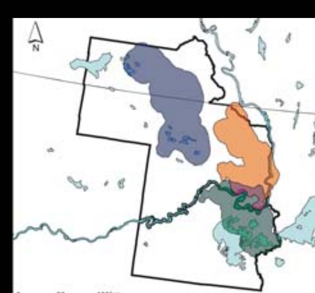
- Little Red River Cree Nation/Tallcree First Nation
- Mikisew Cree First Nation
- Salt River Cree First Nation
- Deninu K'ue First Nation
- Gov't of Alberta Min. Agriculture,
- NWT Dept. RWED,
- Canadian Parks and Wilderness Society
- US Fish and Wildlife Service

- University of Calgary: "Landscape assessment of bison movements in northern Canada: A Contribution to disease risk management"
- University of Saskatchewan: "The limiting effects of bovine brucellosis and tuberculosis on wood bison demography in Wood Buffalo National Park, Canada"

1) Determine disease prevalence in bison in WBNP
2) Determine effect of disease on bison reproduction
3) Determine effect of disease on bison survival
4) Disease-predation interaction

- Bison Captures
  - ~130 bison captured each winter (1997-99)
- Disease testing
  - Brucellosis – serology (CF and BPAT)
  - Tuberculosis – caudal fold and FP
- Radio-telemetry
  - 72-80 radio-collars deployed
  - Relocation frequency ~3 weeks

- Population Delineation
- Logistic regressions: survival and reproduction
  - Akaike Information Criteria
  - Model averaging to address model selection uncertainty
- Age- and sex-structured stochastic population simulation



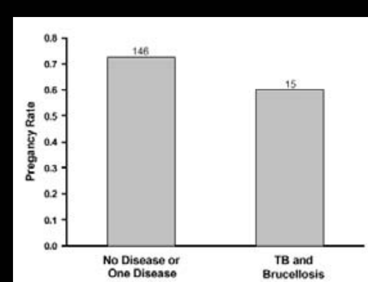
- Determine disease prevalence
- Determine effect of disease on reproduction
- Determine effect of disease on survival
- Disease-predation interaction

Year(s)	Prevalence	Method	Reference
1952-56	40%	post-mortem	Fuller (1962)
1959	14%	OT tuberculin	Choquette et al. (1961)
1983-85	21%	various	Tessaro et al. (1990)
1997-99	49%	PPD tuberculin/FP	this study

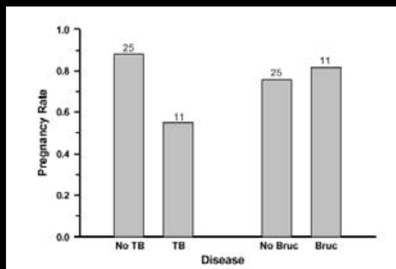
Year(s)	Prevalence	Method	Reference
1959-74	31%	serology	Choquette et al. (1961)
1983-85	25%	various	Tessaro et al. (1990)
1997-99	31%	serology	this study

- Increased with age for both diseases (data not shown)
- Prevalence estimates consistent with previous estimates in WBNP despite a 5-fold decline in population size

- Determine disease prevalence
- Determine effect of disease on reproduction
- Determine effect of disease on survival
- Disease-predation interaction



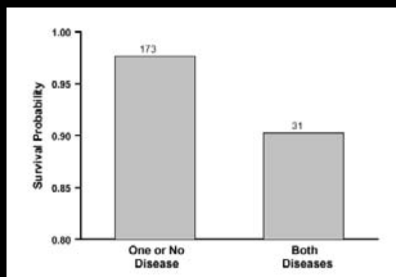
Reproduction – Hay Camp and Delta



Reproduction – Nyarling River

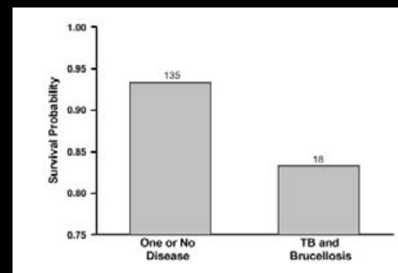
- Interactive effect of brucellosis and tuberculosis. (Hay Camp and Delta)
- Direct effect of TB (Nyarling River)
- Overall low recruitment relative to other populations
  - Calf: cow ratio 28:100

- Determine disease prevalence
- Determine effect of disease on reproduction
- Determine effect of disease on survival
- Disease-predation interaction



Early Winter Survival

Hay Camp and Delta



Late Winter Survival

Hay Camp and Delta

Survival Highlights

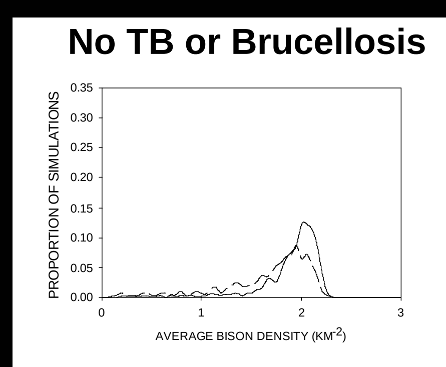
- Interactive effect of brucellosis and tuberculosis
- Predation significant mortality in Delta
- High survival in Hay Camp and Nyarling River

Objectives of Study

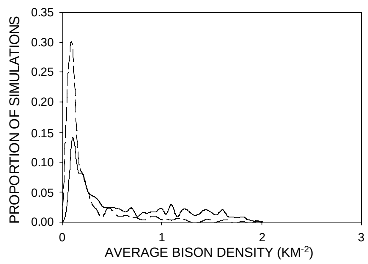
- Determine disease prevalence
- Determine effect of disease on reproduction
- Determine effect of disease on survival
- Disease-predation interaction

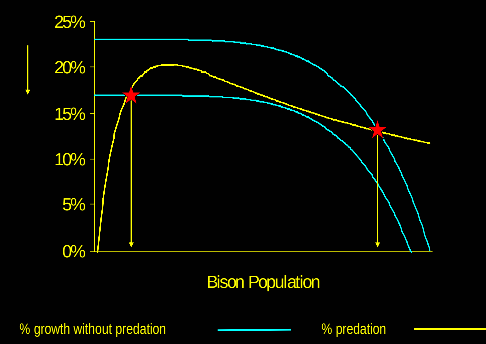
Main Features of Model

- Age and sex-structured
- Discrete time
- Demography data from study
- Hyperbolic numerical and functional responses by wolves
- Stochastic (75 years X 1000 times)



TB and Brucellosis





Summary

- Exotic disease persistence
- Each exotic disease reduces reproduction – either alone or through an interaction
- Diseases interact to affect survival
- Reduction in herd productivity is sufficient to interact with predation to reduce density significantly

Acknowledgements

- Canadian Food Inspection Agency (Lethbridge and Nepean)
- Heritage Canada / Parks Canada
- GNWT, Univ. of Saskatchewan, NSERC
- Todd Shury, DVM
- Amanda Plante, Tim Evans, Trevor Evans, Michelle MacDonald

Department of Primary Industry, Fisheries and Mines

Northern Territory Government

Depopulation for Disease Control

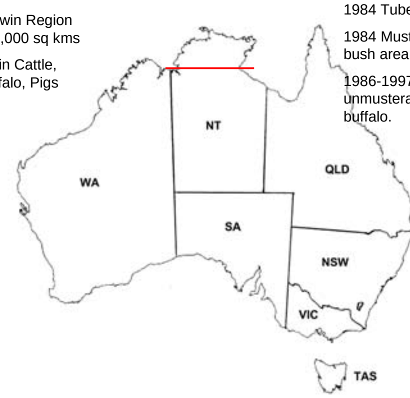
The Northern Territory Experience

Kel Small

Regional Veterinary Officer Darwin

Darwin Region
200,000 sq kms

TB in Cattle, Buffalo, Pigs



TB eradication program

1984 Tuberculin Testing

1984 Mustering infected bush area.

1986-1997 destruction of unmusterable cattle and buffalo.

Summary - 1984 to 1992 for Darwin District

	Mustered	unmusterable stock Destroyed in the field	Total
Cattle	102,000	61,278	163,000
Buffalo	123,000	97,113	210,000

Wagait

1,200 sq kms Cattle, Buffalo, Pigs. Surrounded by fenced cattle herds.

1984,1985, 1986 16,587 cattle and buffalo mustered and sent to abattoirs.

Helicopter shooting of remaining stock commenced late 1986

- Initial helicopter shooting used 4 aircraft Bell 47
- Systematic grid search of 1,200 sq km took 45 hours
- As stock density decreased searching concentrated on high probability areas
- Destocking activity carried out during all seasons of year
- Late dry season – limited water
- Peak wet season flooding – limited high dry ground

- To remove 99% of population required 919 helicopter hours
- To remove last 1% of population required 432 helicopter hours

- Limited use of radio tracking commenced 28/08/1991
- Wet hire rate for Bell 47 helicopter $288 per hour

- Total helicopter cost $389,000
- Destocking was successfully completed and approximately 500 sq km is now fenced and carrying 7,000 head of cattle each dry season.

Wagait stock destroyed helicopter hours

Date	No. of Head	Helicopter Hours	Stock Shot per Hour
28-30/09/1986	869	25	35
02-04/10/1986	866	16	54
09-12/11/1986	901	22	41
14-23/12/1986	6529	180	36
29-31/12/1986	790	37	21
02-26/02/1987	1406	90	16
24-27/03/1987	731	108	7
09-11/06/1987	248	30	8
17-19/06/1987	22	12	2
30/06-02/07/1987	119	29	4
21-23/07/1987	72	35	2
22/09/1987	7	7	1
30/11/1987	17	20	1
01/12/1987	18	20	1
09-11/05/1988	83	28	3
08/07/1988	23	10	2
24-25/05/1989	33	8	4
01-04/09/1990	165	62	2.6
01/12/1990	22	36	0.6
04-06/04/1991	24	18	1.3
11-12/06/1991	10	25	0.4
28/08/1991	8	14	0.6
17/12/1991	37	30	1.2
Aug 1992	26	12	2
Sept 1992	7	45	0.15
Totals	13033	919	Av. 15 / hour

Wagait

Year	No. of Head	Helicopter Hours	Stock Shot per Hour
1993	No activity	-	-
1994	80	227	.35
1995	12	144	.08
1996	20	37	.54
1997	6	24	.25
Totals	118	432	Av. .28 shot per hour

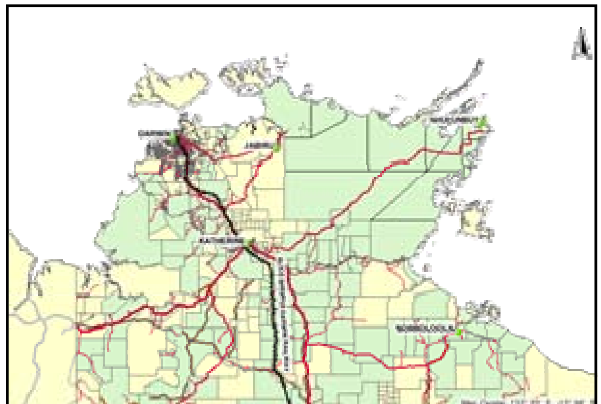
Arnhem Land

Approx. 100,000 sq kms

1985 aerial Survey Buffalo 100,743 Cattle 25,400

- NW Arnhem Land 7.5% TB from abattoir inspection of 6,5000 buffalo
- Southern Arnhem Land 0% TB from abattoir inspection of 15,000 stock
- But 70,000 sq Km was of unknown status in 1983

- Following an aerial survey count of buffalo, cattle and horses in 1983 further survey flights were conducted to determine the relationship between topography and stock distribution.
- A TB eradication program was developed which delineated appropriate boundaries of the major population groups and outlined TB survey requirements.
- Major population groups were surveyed at a level sufficient to result in a probability in excess of 99% of detecting 0.5% TB.
- Where this could not be achieved by mustering then field post mortem examinations of destroyed stock were carried out.
- In 1983 and 1984 1,311 cattle and buffalo were destroyed and examined for evidence of tuberculosis in the field.



North West Arnhem Land

18,900 sq kms

Open floodplain, visually impenetrable vegetation, inaccessible escarpment

1985 count 43,000 buffalo 1,300 cattle ? Pigs

- No infrastructure, limited roads for dry season access
- No boundary fencing separating the monitored negative herds to the east and south
- TB infected
- Destruction of unmusterable stock commenced in 1986
- Following a trial in July 1989 to assess efficiency of Judas cow technique, 60 Judas animal were located in NW Arnhem Land in 1992. at an average density of one per 250sq kms.
- Benefits of radio tracing Judas animals
  - find animals in reduced time and at reduced costs
  - provide information on preferred habitat of individuals and groups
  - movement patterns in relation of seasons
  - relate sign on ground eg tracks, dung, wallows, to a more accurate picture of stock numbers and movements.
- Tracking
  - GPS co-ordinates at last tracking carried, plus frequency of last tracking
  - Audible signal tracked
  - If no signal do a search from high altitude.

DESTOCKING NW ARNHEM

Year	Unmusterables destroyed	
1986	2582	
1987	14073	
1988	12498	
1989	5942 }	(6% located with Judas animals)
1990	3411 }	
1991	609	(85% located with Judas animals)
1992	315	(95% located with Judas animals)

Year	Unmusterables Low land	Helicopter Hrs	Unmusterables Escarpment	Helicopter Hrs
1993	no activity	-	-	-
1994	401	256	70	18
1995	178	178	734	200
1996	136	161	337	167
1997	130	186	220	65

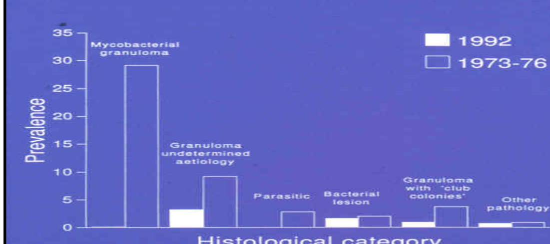


Figure 1. Prevalence of macroscopic lesions resembling Tuberculosis for the 1992 survey (solid bars) and the 1973-76 survey of Corner et al (1981) (open bars)

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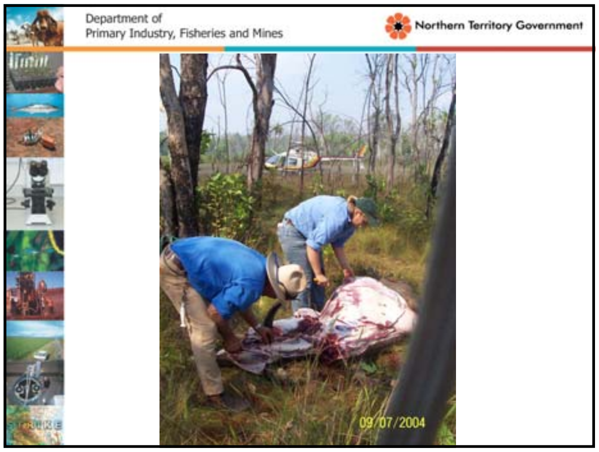

Department of
Primary Industry, Fisheries and Mines
Northern Territory Government
09/07/2004

Wildlife depopulation

Issues and examples

Jim Hone
University of Canberra

Topics

- Aims of depopulation
- Issues
  - Population definition
  - Criteria for success
  - Threshold for disease eradication?
  - How do you know when N = 0?
  - Duration of depopulation?
- Conclusions

Aims of depopulation

- Eradication of a population
- Eradication of a disease
- Conservation of a different species or community

Issues
Population definition

- What is the population in question?
- Is it closed (no immigration, emigration) or open?
- Do land-use boundaries correspond to depopulation boundaries?

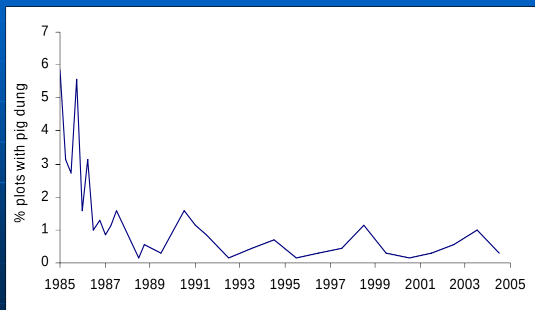
Issues
Criteria for success

- Suggested criteria for eradication (Parkes 1990, Bomford & O'Brien 1995)
- 1. Rate of removal exceeds rate of increase at all population densities
- 2. Immigration prevented
- 3. All reproductive animals at risk
- 4. Animals can be detected at low densities

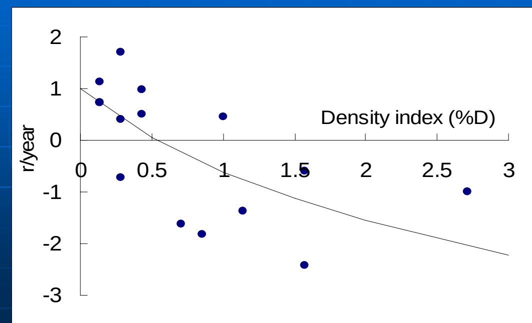
Issues
Criteria for success

- Discounted benefit-cost analysis favours eradication over control
- Suitable socio-political environment
- Evidence for these criteria (1 – 4)?

1. Rate of removal exceeds rate of increase at all population densities; feral pigs in Namadgi National Park, Australia (Hone 2002)



1. Rate of removal exceeds rate of increase at all population densities; feral pigs in Namadgi National Park, Australia (Hone 2002)



Feral pigs in Namadgi National Park

- Rate of removal does not exceed growth rate at all densities
- Immigration could occur from neighbouring land
- Not all reproductive animals at risk (~5% do not eat bait) (Hone 2002)
- Animals can be detected at low densities (but maybe not all densities)
- Conclusion: pigs can not be eradicated

Unsuccessful depopulations

- Control of large mammals for control of tsetse fly-spread disease in southern Africa (Caughley 1977)
- Culling foxes in western Europe to control rabies
- Maybe not all reproductive animals at risk, and depopulation becomes a sustained harvest

2. Immigration prevented

- Real immigration may be preventable
- "Unnatural" immigration may not be preventable
- Red-vented bulbul in Auckland (NZ) may have been eradicated, but may have been later re-introduced deliberately (illegally)
- Discussions to depopulate some wild horses (Australia) usually stop when illegal introductions get mentioned

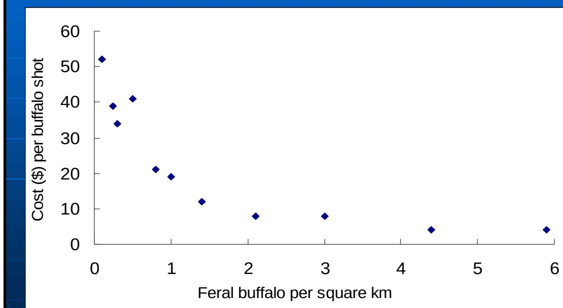
2. Immigration prevented

- Immigration of pathogen may not be preventable
- Rabbit haemorrhagic disease in NZ may have been introduced illegally by farmer(s)

3. All reproductive animals at risk

- As a population is reduced (density decreases) the cost per removal increases
- Can the population be reduced to a low enough level within the budget, and get all reproductive animals at risk?

Shooting of feral water buffalo, Australia (Bayliss & Yeomans 1989)



Buffalo in Kakadu National Park

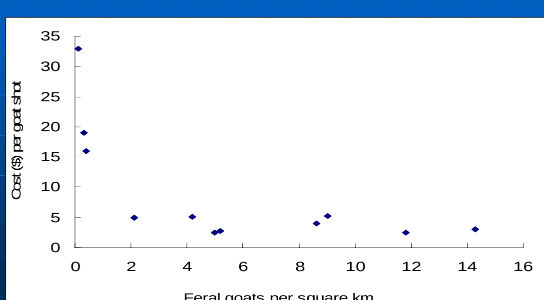
- In 1988, ~20,000 buffalo, and in 1996 there were ~250. Aerial survey estimates
- Intensive depopulation, first by commercial operators, then when not commercially viable by government shooters

Buffalo in Kakadu National Park

- Part of national BTEC (Brucellosis and Tuberculosis Eradication Campaign), 1970-97
- Eradication of buffalo not complete because some not "at risk" (habitat refuges) and social issues
- BTEC successful
- Other wildlife hosts?

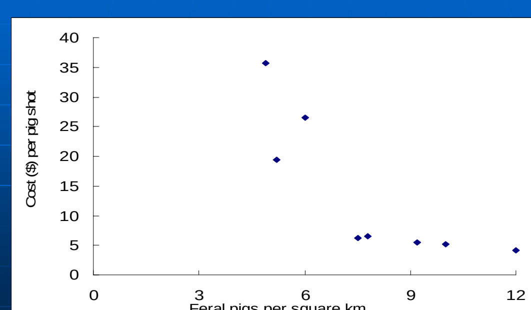
Shooting of feral goats, Australia

(Pople *et al.* 1998)

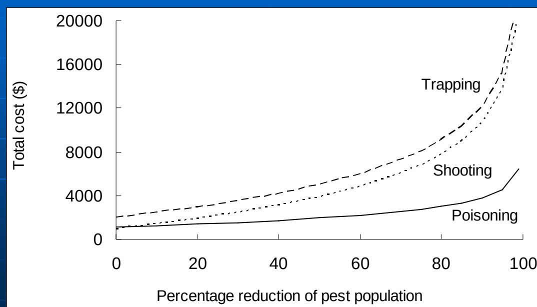


Shooting of feral pigs, Australia

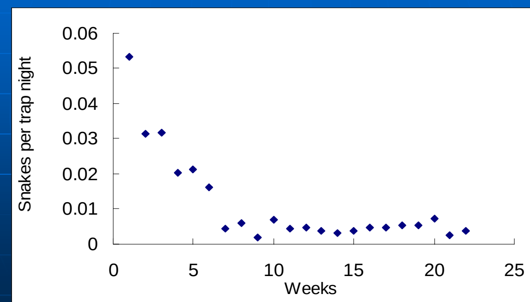
(Choquenot *et al.* 1999)



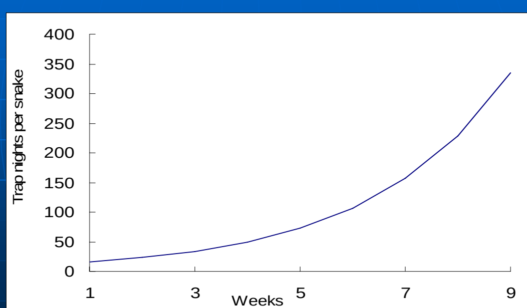
Control of feral pigs, Australia
(Saunders 1988)



Control of brown snakes on Guam
(Engeman *et al.* 2000)



Control of brown snakes on Guam



3. All reproductive animals at risk

- To help achieve the criterion, "smart" bounties may be used
- As N gets low the price paid per removal (the bounty) increases, to maintain incentive and balance increased costs
- Used with coypu eradication in south-east England

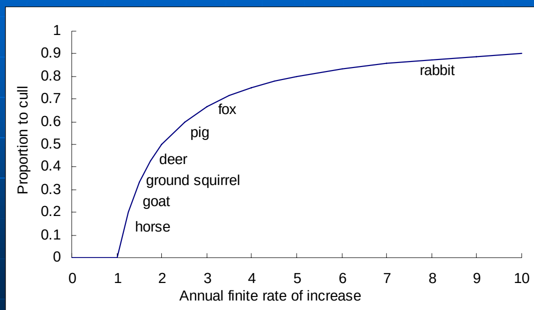
3. All reproductive animals at risk

- Use of set theory
- If depopulation uses 2 (or > 2) methods
- Method 1; 80% susceptible
- Method 2; 70% susceptible
- What percentage are missed by both methods?
- Coverage (spatial), individual heterogeneity

Proportion of population to cull

- The proportion of a population to cull per year (p) to achieve eradication (Hone 1999) is
- $p = 1 - (1/\lambda)$
- where λ = maximum annual finite population growth rate (rate of increase)
- If $\lambda = 1.38$ then $p = 0.27$
- But eradication will take many years (can be estimated)

Proportion of population to cull/yr for eradication



Threshold for disease eradication?

- Does a threshold exist?
- Has it been estimated empirically or by modelling (eg brucellosis in bison in Yellowstone; K_T ~ 200?; 95%CI?)
- Estimated basic reproductive rates (Ro, 95%CI)? Ro ≥ 1 for maintenance host, spill-over host 0 < Ro < 1 ?
- Can these be estimated during depopulation?
- Other wildlife hosts?

How do you know when N = 0?

- Need structured assessment (survey); different method(s) from depopulation
- With increasing duration of no observations, the assessment becomes more confident
- One can estimate; how many sites have to be searched to be 99% (or 99.9%) confident of detecting at least one occurrence?
- Compare with IUCN criteria for "extinct"; no observation in appropriate time frame

How do you know when N = 0?

- Need caution in declaring complete depopulation
- Coypu in south-east England were "eradicated", then another coypu was found (freshly dead) some months later
- Rabbits were "eradicated" from Phillip Island (Australia), then another rabbit found months later

Duration of depopulation

- Duration needs to be longer than the survival time of the pathogen(s). How long?
- If reintroduce animals too early hosts will get reinfected
- If wait too long there is a risk of immigration occurring

Conclusions

- Need to be clear that depopulation criteria can be met, so depopulation can be achieved
- Evaluate any depopulation, using appropriate methods and be cautious about early announcements

References

- Bayliss & Yeomans (1989) Aust. Wildl. Res.
- Bomford & O'Brien (1995) Wildl. Soc. Bull.
- Caughley (1977) Analysis of Vertebrate Populations
- Choquenot *et al*. (1999). Wildl. Res.
- Engeman *et al*. (2000) Inter. Biodeter. & Biodegrad.
- Hone (1999) J. Applied Ecol.
- Hone (2002) Biol. Conserv.
- Parkes (1990) Biol. Conserv.
- Pople *et al*. (1998) Wildl. Res.
- Saunders (1988) MSc thesis. Macquarie University

Tuberculosis and brucellosis in bison

Depopulation

In this discussion, depopulation means **total elimination** of free-ranging bison for a period of time

The use of depopulation to eradicate a disease in wild animals on this scale will be entering unexplored territory

????

What is the actual extent of the area?

-how well defined are the boundaries?

-How porous are the boundaries? (in and out)

How accurate are the estimates of population?

How well can the effectiveness of depopulation be monitored?

What are the likely effects of depopulation?

- On bison (dispersion?)
- On the environment (impact of infrastructure, effect on predators, other ungulates, vegetation)
- On people and public attitudes

What happens to several thousand bison carcasses, many of which will be infected, and all of which are potentially infected.

Special features of WBNP area

- Size and remoteness of area
- Many interests and stakeholders
- Winter
- Wolves, anthrax

Possible methods

- Trapping
- Other mass capture (roundups)
- Hunting individuals (ground, air)
- Judas animals

There will need to be multiple methods used

- Mass capture first and whenever possible
- Selective hunting from the outside in
- Intensive tracking down of individuals
- Use of Judas animals?

Most removal will probably be seasonal (winter)

- vulnerability to trapping
- visibility
-access on ground
- products and byproduct preservation

There will need to be on-going real-time assessment of progress

"adaptive management"

The big problems come at the end

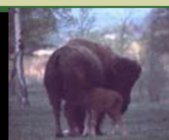
- Huge escalation in cost/ animal removed
- Loss of political interest or "balls" to see it through
- Knowing when success has been achieved.

Repopulation/Genetic Salvage

Overview

- Other bison 'restorations'
- FEARO recommendations
- Hook Lake Wood Bison Recovery Project
- Conservation genetics

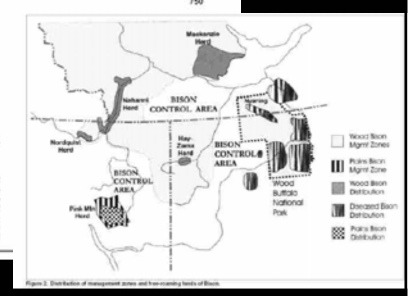
Other bison restorations



- Pink Mountain, British Columbia
  - 50 animals (B. bison bison) released 1971
  - 500 animals by 1990, ~1500 currently
- McKenzie Bison Sanctuary
  - 18 animals 1963
  - rapid increase to 2,000 animals (0.23 instantaneous rate of increase)
  - currently limited by wolf predation, hunting, flooding, habitat limitations
- Hay Zama – 29 wood bison EINP 1984
  - 1993 became free ranging (approx. 450 presently)
  - Currently protected under Alta. Wildlife Act

Table 1. Population size, model estimate, amount of harvesting, and range for the Pink Mountain plains bison population, 1975-present. Courtesy the BC Ministry of Water, Land and Air Protection, 2003.

Year	Population Count	Population Estimate	Harvested Males	Harvested Females	Harvested Juveniles	Total	Number Permits	Annual Range (km²)
1975	50	50						60
1976	70	69.1						450
1977	95	95.6						750
1978	130	132.1						
1979	175	182.7						
1980		201.8						
1981		222.9						
1982		246.2						
1983		272.0						
1984		300.4						
1985		331.9						
1986		366.6						
1987		404.0						
1988		447.4						
1989		494.2						
1990		545.9						
1991		603.0						
1992	648	666.1	43					
1993		692.9						
1994		765.4						
1995		845.4						
1996		933.9	92					
1997		928.7	93.5					
1998		883.8	95					
1999		795.3	22					
2000		826.6	34					
2001		839.1	45					
2002		824.9	12					
2003	876	874.2						



What has worked?

- 'Soft' release of young translocated bison (calves & yearlings) seems to work in most situations
- Increase in herd size are initially rapid especially if habitat conditions are favourable (low predation, C. atherodes)
- Virtually all reintroduced bison have originated from Elk Island National Park with small founder popns

FEARO recommendations

25. The panel recommends that replacement stock come primarily from Elk Island NP.
    - limited genetic salvage from involving small (20) groups with testing to ensure disease-freedom.

26. …that a non-governmental organization within the WBRT be approached to oversee the salvage operation.

27.…that five breeding stations be established, four of them outside WBNP (SW corner), and one inside (Hay Camp).
    - to be turned over to local ownership after repop.

28. …that the financial requirements and sources for the implementation of the preferred option be re-examined once the detailed design of the program is complete.

Year	Site 1	Site2	Site 3	Site 4	Site 5	Total
Founders	80	40	40	40	40	240
0	**98**	•	•	•	•	**98**
1	121	**49**	•	•	•	170
2	154	62	**49**	•	•	265
3	192	80	62	**49**	•	383
4	239	102	80	62	**49**	532
5	300	129	102	80	62	673
6	378	160	129	102	80	849
7	473	199	**160**	129	102	1063
8	593	248	199	160	129	1329
9	742	311	248	199	160	1660
10	930	390	311	248	199	2078
11	1165	487	390	311	248	2601
12	1458	610	487	390	311	3256
13	1828	763	610	487	390	4078
14	2283	954	763	610	487	5097
15	2857	1194	954	763	61.0	6378

Table 1 Repopulation Scenario.
Projected growth of founder populations based on the availability of 80 animals in the first year for Site 1 and 40 animals **per** year for the next four years to be available for other sites. Assumptions of the model are: that 25% of each shipment will be cows in calf; the sex ratio of the founders is 1:1; conception rate is 90%; survival to age 27 months is 90%; females breed at about 27 months and annually thereafter; adult mortality is 2% per year.

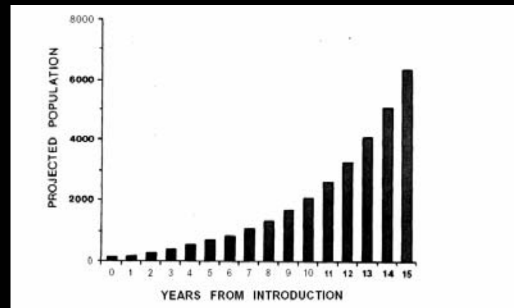


FIGURE 7 Projected growth of founder population.

IUCN

SSC

Conservation Genetics

IUCN Species Survival Commission
- Bison SG
- Reintroduction SG \\Cgy-files\users$\Todd Shury\Bison\Bison Diseases Workshop 2005\IUCN reintro guidelines.htm

Maintenance of genetic diversity
- only means by which popns can respond to selection in future
- Potential bank of alleles for commercial bison

Primary measures: Heterozygosity & Allelic diversity

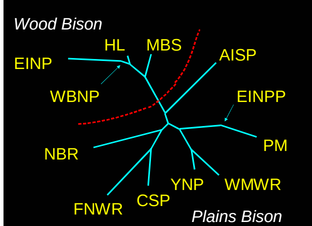
Genetics

Min. 50 individuals required to salvage genetics (Pink Mtn, Hook Lake, MBS, EINP – Wilson & Strobeck 1999)

More important to use large # of founders regardless of origin (Wilso & Strobeck 1999)

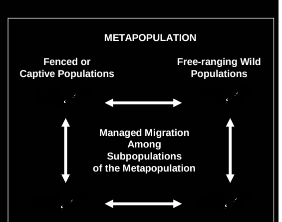
Some plains bison genes throughout WBNP, more bison assigned to PB pool from Sweetgrass area

Genetic Salvage & Captive Breeding



Wilson and Strobeck 1999, G. Wilson 2001

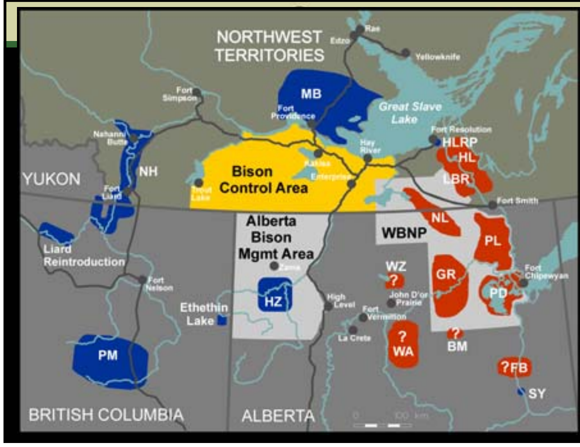
Gene Flow within a Metapopulation

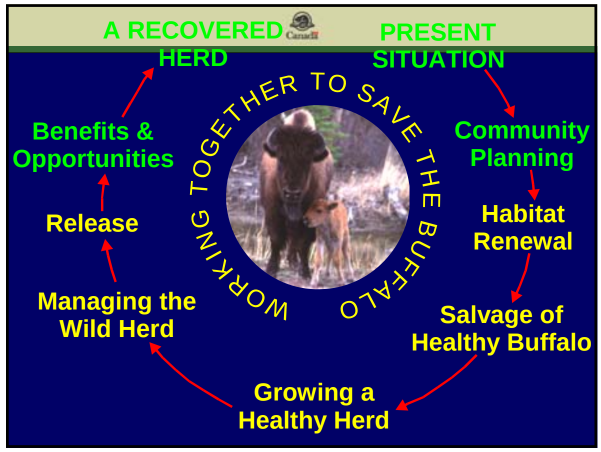


Adapted from Ballou et al. 1995

Hook Lake Wood Bison Recovery Project

Unique wood bison salvage project
Others proposed, only carried out to date
Captured 2 wk old calves 1996-98
Test negative for Brucella (BCT)
Bottle fed milk replacer with antibiotics (5 mos)
Housed in pairs in isolation pens for 10 mos





Phase 2: Salvage & Captive Breeding

1) orphaning
2) prior testing of calves in the field
3) isolating calves
4) prophylactic treatment
5) intensive whole-herd disease testing
6) isolation & testing for latency @ 3 days & 4 weeks post calving

Founders

1996 (7 Yr-olds):	13 females	5 males
1997 (6 Yr-olds):	16 females	4 males
1998 (5 Yr-olds):	14 females	5 males
TOTAL:	43 FEMALES	14 MALES

Disease treatment

5) Disease Testing:

Two whole herd tests / year (Nov & Feb)

- **Tuberculosis: Caudal fold (PPD) & Comparative cervical & FPA***
- **Brucellosis: BPAT, STAT, CFT, cELISA, FPA***

TB-infected bison herd to be slaughtered

An entire herd of 122 bison in the Northwest Territories will be slaughtered, a decision that comes two months after a young calf in the herd tested positive for highly contagious Bovine Tuberculosis. The Canadian Food Inspection Agency fears the herd, located in Fort Resolution, will become infected.

CBC New July 18, 2005

Lessons learned

- Live animal genetic salvage with disease elimination is possible
- Costs are substantial
- Must balance need for genetic conservation with disease eradication goals (esp. for TB)
- Community support and involvement are critical
- Need for pre-defined criteria for establishing disease-free status prior to release into wild (CFIA protocol?)

In summary.....

- Current evidence supports WBNP metapopulation linked demographically & genetically (Joly & Messier 2001, Wilson 2001)
- Genetic testing of some herds (SW herds) as no testing to date
- Hook Lake herd is most genetically diverse, but still not as diverse as WBNP popn (Wilson 2001)
- Genetic salvage by two primary means: live animals or Advanced Repro Techniques (ART)

Other initiatives

- ART Research at U of Sask
  - Phase 1 – characterize reproductive cycle using ultrasonagraphy (250K), paucity of research in this area (4 studies)
  - Phase 2 – Refine advanced ART (AI, IVF superovulation, embryo transfer, cryopreservation) for bison
- Model for what needs to be done prior to germplasm salvage using in vitro techniques
- i.e harvest spermatozoa & oocytes post-mortem - cryopreserve

Key Questions

Goal: to re-establish viable, TB and brucellosis-free wood bison populations with at least as much genetic diversity as currently exists.

1) Genetic salvage: live animal or ART, test & slaughter feasibility, min. # to salvage 90-100% allelelic diversity
2) Logistics: # founders, locations, time frame, source population(s)

Key Questions

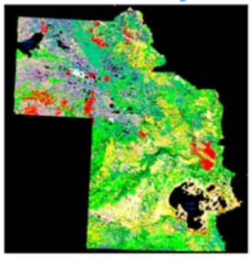
3) Measures of success: repop to current popn level?, time-frame for different levels, how to ensure genetic diversity captured, how to ensure continued disease-freedom?

4) Questions: what scientific & technical questions need to be addressed prior to repop? Loss of learned behaviours?

5) Other diseases to consider: Johnes, BVD, anthrax, others

6)Cost estimates for each scenario

Wood Buffalo National Park Ecosystem Risk Analysis



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Institute of Environment/l'Institut de l'environnement 01

Modeling Ecological Impacts of Repopulation / Depopulation

A joint endeavour by

Parks Canada

Little Red River / Tall Cree First Nation

University of Ottawa

Institute of Environment/l'Institut de l'environnement 02

The Tasks and the Non-Tasks

Estimate risks to identified valued ecosystem components (species, habitats) under a range of depopulation and repopulation strategies.

Produce a tool that will allow managers (and others) to explore the ecological consequences of different de-populaton / re- population scenarios.

Model spatio-temporal dynamics of disease.

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The General Modeling Approach: Constraints & Requirements

1. Must be able to accommodate different sets of endpoints.

2. Must be able to accommodate different de-population / re-population scenarios.

3. Need not require detailed and extensive data to parameterize relationships between model components.

4. Must accomodate the generally high uncertainty in estimated relationships (predator/prey/grazing): consequently, the model cannot distinguish (empirically) between competing models.

5. Must be spatially explicit (at some scale).

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What's Going On?

The bison of WBNP are infected with brucellosis and tuberculosis.

One of the proposed solutions to this situation is to cull the current bison population and replenish WBNP in the near future, with uninfected stock.

- The bison is an important component of the WBNP ecosystem. What are the risks associated with such an endeavour?
- In particular, how will the other populations of the ecosystem react to the abrupt change a culling will bring about?
- Can mathematical modeling help us make an informed decision?

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The Players

The model studies the interactions of 10 components of the WBNP ecosystem.

- **Animal Species:**
  - Bison, Caribou, Moose
  - Wolf
- **Habitat Types:**
  - Deciduous Vegetation
  - Fen
  - Grasslands
  - Pine
  - Spruce
  - Willow / Sedge

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Six Postulates of Ecology

Following Turchin [2003], we present a list of 6 ecological postulates we feel any ecological model hoping for relevance should follow.

P1- Conservation.
The number of organisms in a population can change only as a result of births, deaths, immigrations and emigrations.

P2- Methodological Individualism.
The population processes affecting population change are individual-based.

P3- Upper Density Bound.
There is an upper bound beyond which population density cannot increase.

P4- Mass Action.
At low resource densities, the number of resource individuals encountered and captured by a single consumer is proportional to resource density.

P5- Biomass Conversion.
The amount of energy that an individual consumer can derive from captured resource and use for growth, maintenance and reproduction, cannot be higher than the product of the energy contained in the resource and a maximum conversion rate particular to the consumer species.

P6- Maximum Consumption Rate.
No matter how high the resource density is, an individual consumer can ingest resource biomass no faster than some upper limit imposed by its physiology.

The Traditional Approach

Usually, ecosystem evolution is modeled *via* systems of ordinary differential equations (ODE) or partial differential equations (PDE). These are known as **continuous population models**.

Let N(t) and P(t) represent respectively the population density of a prey species and of a predator species in an ecosystem at time t.

The derivatives of N(t) and P(t) with respect to time t are the **per-capita growth rates** of these populations in the ecosystem.

We recover N(t) and P(t) by solving ordinary differential equations:

$$\frac{dN(t)}{dt} = N(t)F(N(t), P(t))$$

$$\frac{dP(t)}{dt} = P(t)G(N(t), P(t))$$

where the functional forms of F and G depend on the species and their particular interactions.

Predator-Prey Models

Lotka-Volterra (LV):

$$\frac{dN(t)}{dt} = N(t)(a - bP(t))$$

$$\frac{dP(t)}{dt} = P(t)(cN(t) - d)$$

$$a, b, c, d > 0$$

Analysis:

(i) the prey grows unboundedly in the absence of predators (unrealistic);

(ii) predation reduces the prey's per capita growth rate by a term proportional to the prey and predator populations (realistic);

(iii) the predator's decay is exponential in the absence of prey (unrealistic);

(iv) the prey's input into the predator's per capita growth rate is proportional to the prey and predator populations (realistic).

(v) LV exhibits out of phase periodic cycles, which have been observed in Nature.

Spatial Ecology (I)

Dispersion / Migration.
In LV models, the underlying environment is assumed to be uniform, and as such, spatial considerations are negligable.

In an ecosystem such as WBNP, this is not the case. When a species' favorite foodstuff becomes scarce, the species is unlikely to let itself go extinct, rather it will forage and look for newer sources, perhaps in a physically distinct region.

Furthermore, many species are known to migrate large distances to a favorite spot, in time for the reproductive season.

Random foraging movement is often modeled by diffusion. The resulting model obtained by combining spatial effects with predator-prey interactions fall in a class of PDE called reaction-diffusion systems (RDS).

Such systems have been studied in the context of cardiology and excitable media; their application to ecology is just as important.

Spatial Ecology (II)

Reaction-Diffusion System:

$$\frac{\partial U(x,y,t)}{\partial t} = F(U(x,y,t)) + D\nabla^2 U(x,y,t)$$

where U(x,y,t) is the density population vector at the spatial location location (x,y) and time t, $D\nabla^2$ is the weighted Laplacian operator and F is a reaction term.

LV-modified RDS:

$$\frac{\partial N(x,y,t)}{\partial t} = N(x,y,t)(a - bP(x,y,t)) + D_1\nabla^2 N(x,y,t)$$

$$\frac{\partial P(x,y,t)}{\partial t} = P(x,y,t)(cN(x,y,t) - d) + D_2\nabla^2 P(x,y,t)$$

where a,b,c,d are as before, D_1 and D_2 are non-negative diffusion coefficients and N(x,y,t), P(x,y,t) represent the population density of the prey and predator species at the spatial location (x,y) and at time t.

So What's Wrong with PDE?

First, the objections raised in LV still hold.

The reaction terms in the RDS are open to interpretation: what functional forms are appropriate for what species? For instance, logistic growth can be applied to certain mammals, but regrowth is best reserved for certain plants. But which?

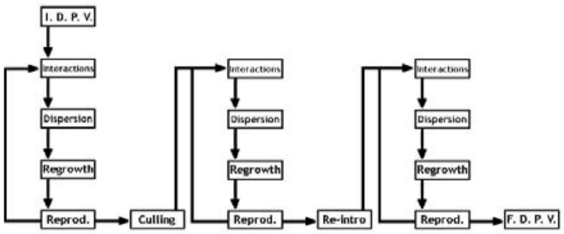
It is also not clear that diffusion is the favoured mode of dispersion for some species.

Furthermore, a lot of parameters must be known with a certain degree of precision in order to make sense of the solutions of the RDS.

Finally, culling introduces discontinuities into the model. We cannot even be sure that the modified RDS will have a solution, or that any solution will have a meaningful quantitative interpretation!

This leads us to consider instead discrete systems, but (and that is an important mathematical point) these are not dynamical systems.

The Process



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The Process Flow

- The model input is the initial density population vector (IDPV).
- Each run through a stack corresponds to 1 time-step, or 1 model season.
- 4 model seasons = 1 model year.
- Stack **A** models the ecosystem's evolution *pre*-culling.
- After l_1 seasons, bisons are culled from the ecosystem.
- Stack **B** models the ecosystem's evolution *post*-culling, but *pre*-re-introduction of healthy bisons.
- After l_2 seasons, bisons are re-introduced into the ecosystem.
- Stack **C** models the ecosystem's evolution *post*-re-introduction of healthy bisons.
- After l_3 seasons, the model outputs the final density population vector (FDPV).

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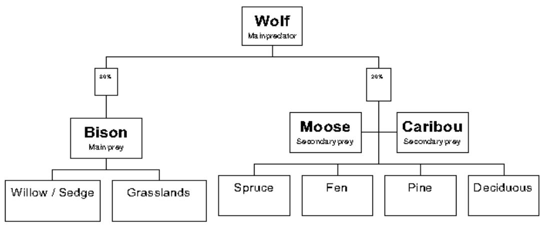
Predation Diagram



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Fuzzy Cognitive Maps Quantitative vs Qualitative

Our approach is to eschew quantitative analysis at this stage and to focus on a qualitative interpretation, which we borrow from the theory of Fuzzy Cognitive Maps (FCM).

- Consider a predator-prey ecosystem: the prey density is denoted by N, while the predator density is denoted by P.
- We might not all agree as to how to describe the dynamics of this ecosystem. What can we agree on?
- On a very basic level, it seems plausible that if N increases, so will P. In other words, if the prey density increases, there is more prey available for the predators to feed on, which should in turn lead to more newborn predators down the road. Similarly, if N decreases, so should P.
- On the other hand, if P increases, then N should decrease. Indeed, if there are more predators in the ecosystem, then more preys should be killed and consumed, bringing their density down. Similarly, if P decreases, N should increase.

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Expressing FCM Mathematically

We turn to the language of matrices to describe the preceding situation.

	Pred.	Prey
Pred.	0	+
Prey	-	0

When the prey density increases, so does the predator density. T This is denoted by a positive value in the (1,2)-entry of the matrix.

When the predator density increases, the prey density decreases. This is denoted by a negative value in the (2,1)-entry of the matrix.

By convention, all entries in the diagonal are set to 0.

The values all fall in the interval [-1,1]. For instance, we could have +1 in the (1,2)-matrix entry and -1 in the (2,1)-entry. This would lead to the following computation:

$$\begin{bmatrix} P_1 \\ N_1 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} P_0 \\ N_0 \end{bmatrix} + \begin{bmatrix} P_0 \\ N_0 \end{bmatrix} = \begin{bmatrix} P_0 + N_0 \\ N_0 - P_0 \end{bmatrix}$$

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Expressing FCM Mathematically (II)

Quantitatively, this does not say much, as the scales of P and N might not be well matched, but qualitatively, it tells us that after one time-step, the predator density increases and the prey density decreases.

In general, when these correlation values are *near* 1 in absolute value, we say that the (directed) interaction is **strong**. If it is *near* 0 in absolute value, we say that the (directed) interaction is **weak**.

When there is no known correlation between two species, the corresponding matrix entry is 0.

To better grade the interaction's strength, we chose a resolution level, and divide the intervals [-1,0] and [0,1] into equal parts.

Strong (-) Weak(-) Neutral Weak(+) Strong(+)

-1 -0.75 -0.5 -0.25 0 0.25 0.50 0.75 1

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Expressing FCM Mathematically (III)

Our aim is to gather up as many blocks from the Process as possible in this FCM.

Some of the model aspects have resisted our first attempts at qualitative description, namely plant regrowth and spatial considerations.

At this stage, the model can only include them, but it's a marriage of convenience.

These still need to be translated into the FCM in order to complete the model, however, at least two new leads are being investigated as we speak.

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WBNP FCM

w_1=Wolf	0	+	+	+	0	0	0	0	0	0
w_2=Bison	–	0	0	0	+	+	0	0	0	0
w_3=Moose	–	0	0	0	0	0	+	+	+	+
w_4=Caribou	–	0	0	0	0	0	+	+	+	+
w_5=Will./S.	0	–	0	0	0	0	0	0	0	0
w_6=Grassl.	0	–	0	0	0	0	0	0	0	0
w_7=Spruce	0	0	–	–	0	0	0	0	0	0
w_8=Pine	0	0	–	–	0	0	0	0	0	0
w_9=Decid.	0	0	–	–	0	0	0	0	0	0
w_{10}=Fen	0	0	–	–	0	0	0	0	0	0

Model Parameters and Densities

We divide WBNP *via* a 50 x 50 array: in effect each grid cell encompasses an geographical region with area approximatively 25 sq. km.

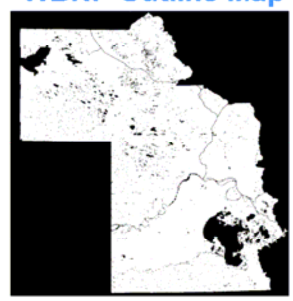
With these measurements, we assume the following (grossly exaggerated) maximal capacities for each grid cell:

- **Bison:** 800 individuals / 25 sq. km.
- **Moose:** 200 individuals / 25 sq. km.
- **Caribou:** 200 individuals / 25 sq. km.
- **Wolf:** 40 individuals / 25 sq. km.

For instance, a bison density of 0.1 means that 80 bisons are found in the grid cell, while a wolf density of 0.1 indicates that 4 wolves are located in the grid cell.
The initial populations are taken from the 1999 Survey.

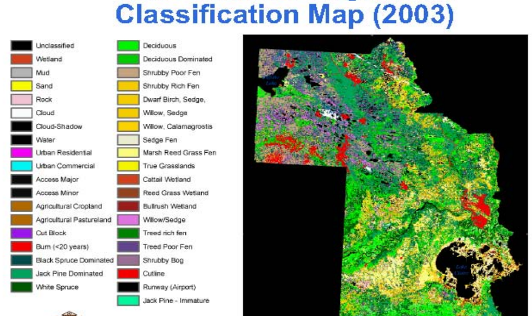
Habitat type densities behave on a proportional level, based on Jensen's map. For instance a fen density of 0.2 means that fen makes up 20% of the vegetation in the grid cell.

WBNP Outline Map

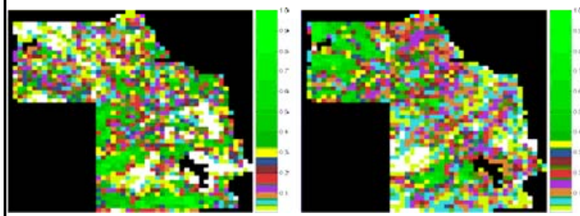


WBNP Model Map (50 x 50)

Olaf Jensen's Vegetation Classification Map (2003)

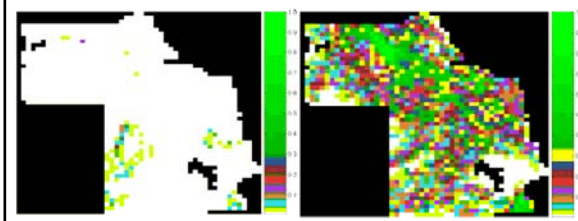


WBNP Model Maps (50 x 50) Initial Conditions (I)



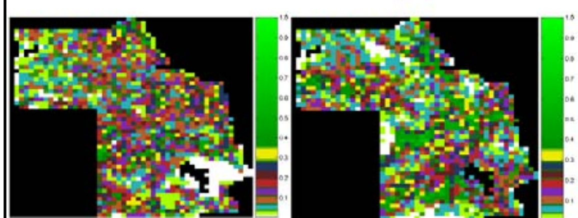
Deciduous Vegetation   Fen

WBNP Model Maps (50 x 50) Initial Conditions (II)



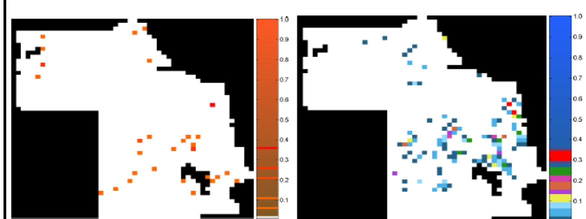
Grasslands   Pine

WBNP Model Maps (50 x 50) Initial Conditions (III)



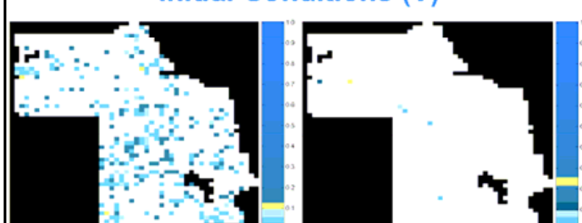
Spruce   Willow / Sedge

WBNP Model Maps (50 x 50) Initial Conditions (IV)



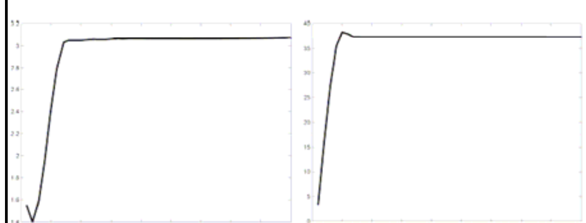
Wolf "Density"   Bison "Density"

WBNP Model Maps (50 x 50) Initial Conditions (V)

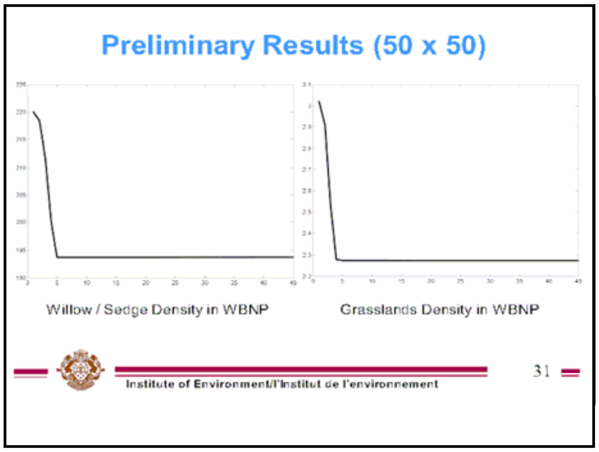


Moose "Density"   Caribou "Density"

Preliminary Results (50 x 50)



Wolf "Density" in WBNP   Bison "Density" in WBNP


Preliminary Results (50 x 50)
Willow / Sedge Density in WBNP
Grasslands Density in WBNP
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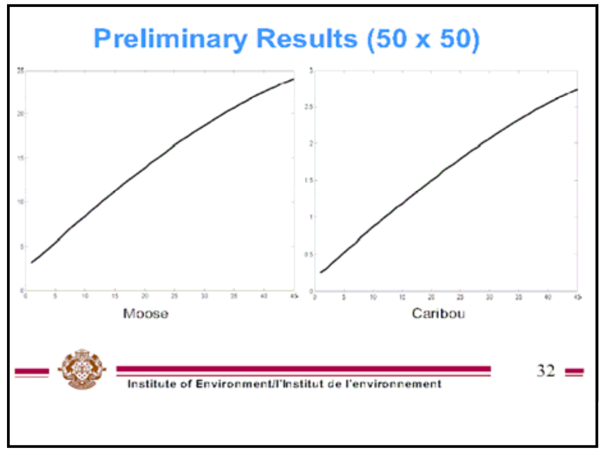
Preliminary Results (50 x 50)
Moose
Caribou
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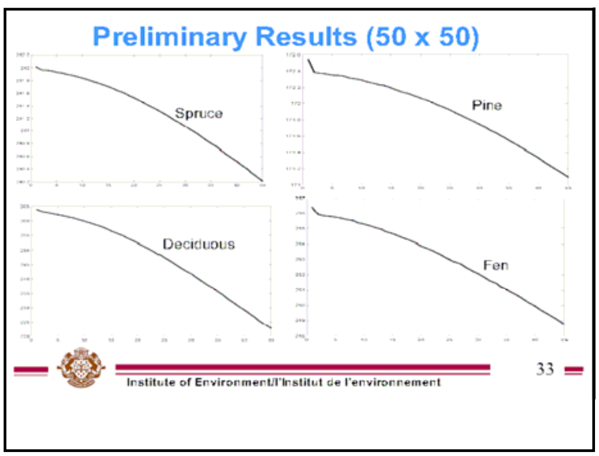
Preliminary Results (50 x 50)
Spruce
Pine
Deciduous
Fen
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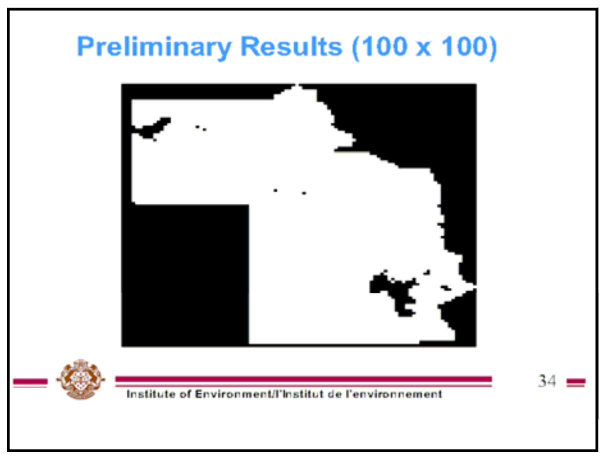
Preliminary Results (100 x 100)
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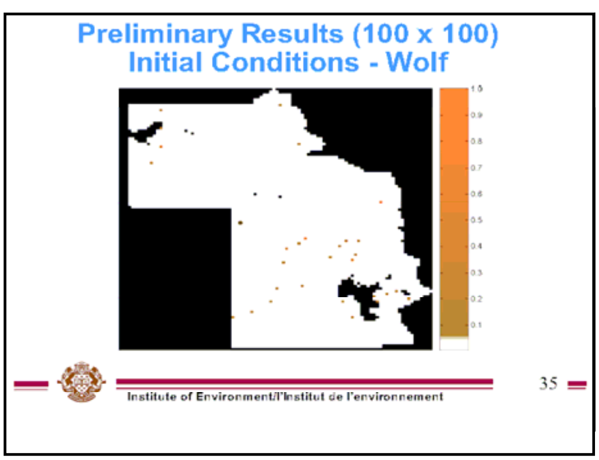
Preliminary Results (100 x 100)
Initial Conditions - Wolf
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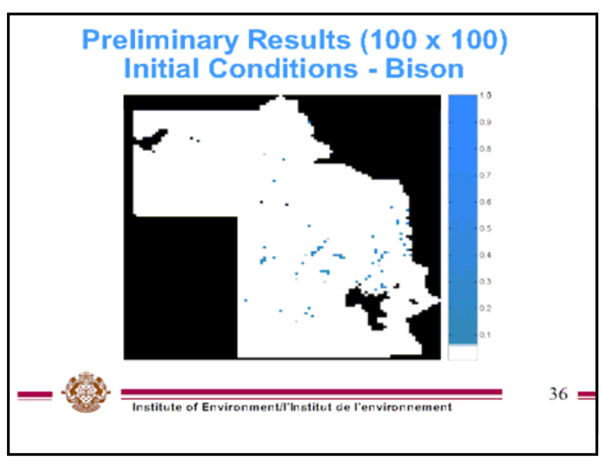
Preliminary Results (100 x 100)
Initial Conditions - Bison
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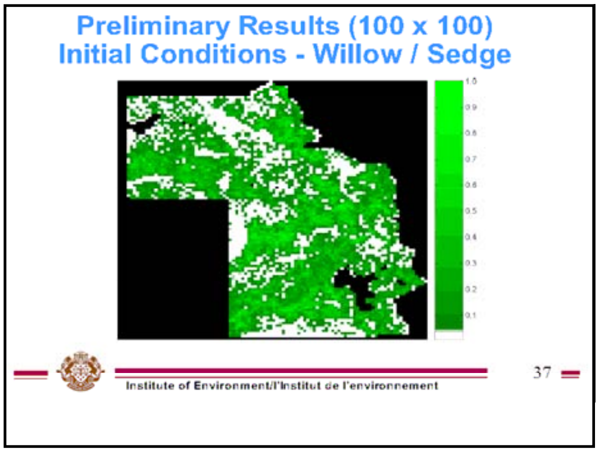
Preliminary Results (100 x 100)
Initial Conditions - Willow / Sedge
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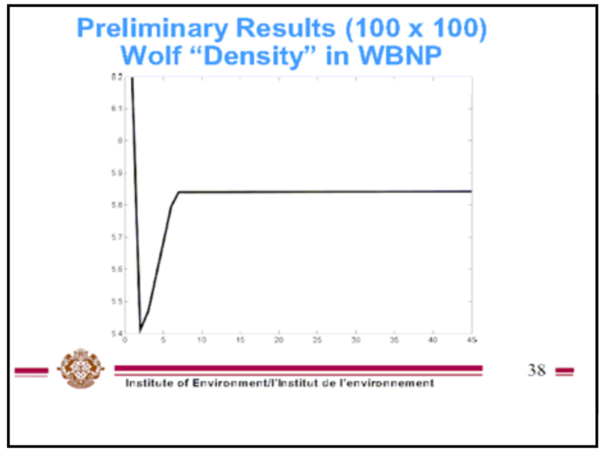
Preliminary Results (100 x 100)
Wolf "Density" in WBNP
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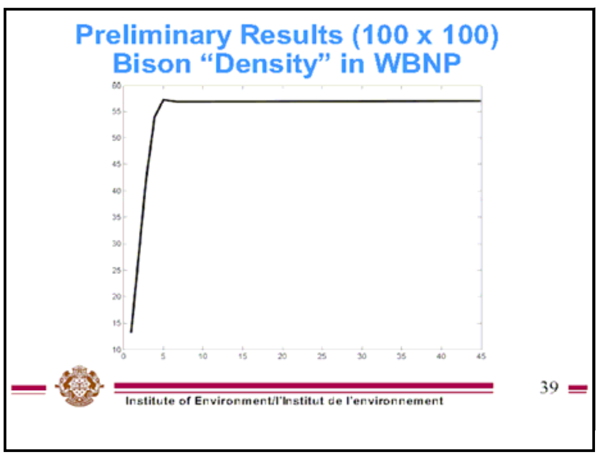
Preliminary Results (100 x 100)
Bison "Density" in WBNP
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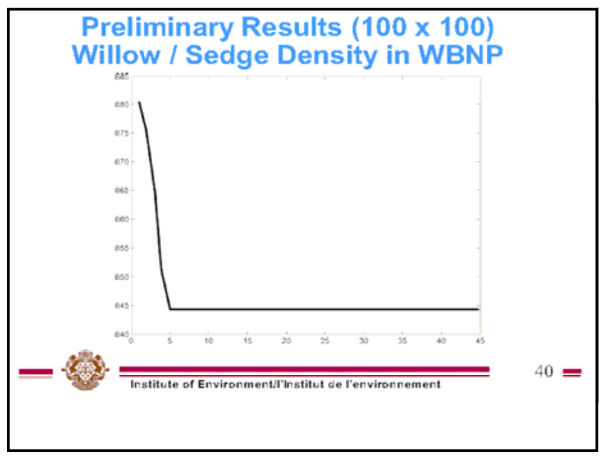
Preliminary Results (100 x 100)
Willow / Sedge Density in WBNP
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