

**HEALTH ASSESSMENT AND MANAGEMENT RESOURCE FOR SPECIES AT RISK
IN BRITISH COLUMBIA**

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Executive Summary

Health risks to wildlife populations are many and varied and can create significant obstacles to the recovery of a wide variety of species at risk. As a result, recovery teams and wildlife managers need a set of broadly applicable tools at their fingertips to assess and manage the health of species at risk including methods to assess population and individual animal health, information on sampling methodology, and testing protocols, handling guidelines, contact information for wildlife health specialists, and risk assessment tools for animal translocations. Disease is a particularly important determinant of wildlife health not only for its ability to cause dramatic mortalities in wildlife populations but also for its population regulating impacts (Section 2.b). By disease we are referring not only to infection with a bacterium, virus or parasite but any physiological or psychological dysfunction (Last 2001).

This document has three primary areas of focus: 1) a description of health and its potential impact on wildlife populations (sections 2 and 3), 2) methods of assessing the health of species at risk populations (section 4), and 3) how to incorporate health assessment findings into recovery strategies (sections 4e and 5).

A number of risk assessment models are already available to evaluate and manage disease in wildlife and domestic livestock populations (e.g. CFIA¹ OMAFRA², OIE³). However, these models often focus on specific disease agents and animal movement events and usually require very detailed information about the prevalence and distribution of these agents in the species of concern. Here we present a more generalized assessment model for evaluating population health that allows for health monitoring and mitigation actions to be tailored to a population's overall level of risk. The nature and magnitude of recovery initiatives depend on the current status of the species at risk population and the nature of identified health hazards. We have identified three action modes for management and recovery of species at risk (Figure 3).

Assessment of the health status of species at risk is an adaptive or iterative process whereby a population's risk level must continually be monitored as health risks may change and shift the population into another category with different health-related actions. Ongoing assessment provides wildlife biologists, managers and planners with the tools to know if, when, and what action is required and when that action needs to be adapted to meet the identified changes in species at risk status or risk factors. There are a variety of tools available to assess the health of domestic animals and, in general, the same tools can also be used to assess the health of wildlife populations. Although the same tools are available, in many circumstances the tests have not been validated in wildlife species. Consequently, there are important limitations to be aware of when interpreting test results. Section 4.c. outlines a range of health assessment tools that can be applied to both live (Table 6) and dead (Table 7) animals.

Once the health of the population at risk has been assessed, the findings can be incorporated into a recovery and management plan. The results of the health

¹ <http://www.inspection.gc.ca/english/sci/ahra/rianfrwk/rianfrwke.shtml>

² <http://www.omafra.gov.on.ca/english/research/risk/frameworks/as2.html>

³ *Scientific and Technical Review*, Vol. 14 (4), December 1995

assessment should enable wildlife managers to identify and set goals for the species at risk populations. The goals will reflect what is expected from the wildlife population in question. Expectations for a given population may include one or more of the following: reduction or elimination of disease, re-establishment of a wild population, maintenance of genetic diversity, and maintenance or improvement of economic production (hunting, fishing, tourism, etc). Whether it is possible to achieve these objectives, and if so how, will depend on the wildlife population in question, the habitat in which they live and the nature of the health hazard that threatens or is already having an impact on the population. Nevertheless, some general suggestions of health-related actions that could be incorporated into wildlife management plans are described in section 4.e.

It is essential that monitoring continue once a recovery plan has been developed and implemented. Ongoing monitoring and health assessment of species at risk is necessary to determine whether the recovery plans are having a positive impact on the species at risk populations, to identify areas where problems may exist in the recovery plans, to adapt the recovery plan to improve success and deal with potential problems, and to identify any new or re-emerging health threats to the population in question. Any management plan must be adaptable so that as new information becomes available it too can be incorporated and recovery plans adapted to reflect our new understanding of the complex host-agent-environment web. Adaptive management is critical to success.

Introduction

Wildlife disease can create significant obstacles to the recovery of a wide variety of species at risk. Disease can have obvious (e.g. large scale die-off) and subtle (e.g. reduced fecundity, survival and fitness) impacts on wild populations and both may affect the speed, success and feasibility of recovery programs and actions. However, disease is just one of many known and unknown hazards that can negatively impact the health of species at risk. Many wildlife biologists and managers have recognized that the success of species at risk recovery initiatives would be greatly enhanced through the incorporation of effective health assessment and management plans as integral components of species at risk recovery strategies. Successful incorporation of health issues into recovery plans is difficult, however, because the health status of many B.C. wildlife species is unknown; little information exists on their habitat requirements, response to human development and susceptibility, immunity and response to many diseases, infectious or otherwise. Incorporating health issues into species at risk management plans when so little is known about health and disease in these populations can pose several challenges. Recovery teams need at their fingertips a set of broadly applicable tools to assess and manage the health of species at risk including methods to assess population and individual animal health, information on sampling methodology, and testing protocols, handling guidelines, contact information for wildlife health specialists, and risk assessment tools for animal translocations.

The objective of this document is to provide a resource tool for wildlife biologists, managers and planners to improve management and recovery planning of species at risk in British Columbia through the integration of health assessment and management techniques. This document has three primary areas of focus: 1) a description of health and its potential impact on wildlife populations, 2) methods of assessing the health of species at risk populations, and 3) how to incorporate health assessment findings into recovery strategies. The information included in this resource was derived from peer-reviewed journals, personal communications, relevant websites, books and manuals.

Why do we need to consider the health of species at risk?

2.a. *What is health?*

The word health originates from the old English word 'hal' meaning 'whole, sound in wind and limb'. Health was long considered to be the absence of disease but is no longer viewed in this overly simplistic way. Although disease remains an important factor influencing health, today there are a variety of definitions (Box 1) that use terminology such as integrity, equilibrium, well-being, adaptability, and ability to meet needs and cope with stresses. Health can be viewed as the sum of attributes necessary for survival as well as for achieving expected roles.

Box 1: Sample of health definitions (Last, 2001)

The extent to which an individual or a group is able to realize aspirations and satisfy needs, and to change or cope with the environment. Health is a resource for everyday life, not the objective of living; it is a positive concept, emphasizing social and personal resources as well as physical capabilities. (WHO 1984)

A state characterized by anatomic, physiologic and psychological integrity; ability to perform personally valued family, work and community roles; ability to deal with physical, biologic, psychological and social stress; a feeling of well-being; and freedom from the risk of disease and untimely death.

A sustainable state in which humans and other living creatures with which they interact can coexist indefinitely, in equilibrium.

In domestic livestock, individual animal and population roles are relatively easy to define as they are largely based on economic performance. A 'healthy' dairy cow is one that is able to reproduce at expected intervals and produce an expected amount of milk on a daily basis. Should that cow have an infectious disease (e.g. mastitis) or suffer from malnutrition, she will not be able to achieve the objectives we have set for her in terms of milk production. Similarly, a 'healthy' pig herd is one that achieves optimal measurable parameters such as fertility rate, days from birth to market, feed conversion ratio and so on. However, wildlife health is not nearly as straightforward to define. Ecological, social and economic roles of wildlife in our society are many but are often difficult to characterize. The wide breadth of wildlife roles frequently means that the health of wildlife is put in jeopardy by human activity. In return, changes in wildlife health can have an important impact on the health of humans and domestic animals (Table 1).

Table 1. Ecological, social and economic roles of wildlife and their impact on the health of humans, livestock, other wildlife and themselves.

	Ecological roles	Social roles	Economic roles
Issues	<ul style="list-style-type: none"> ◆ Wildlife diversity influences ecosystem productivity and services such as seed dispersal, maintenance of soil fertility and quality, maintenance of habitat physiognomy, recycling of nutrients (scavenging and food transport), and limits disease propagation (predation). ◆ Traditionally, wildlife disease has been viewed as a natural component of wildlife ecology, causing peaks and troughs in population size. Ecosystem alteration, fragmentation and alien species introductions have dramatically changed the role of wildlife disease in regulating populations and introducing or amplifying pathogens. 	<ul style="list-style-type: none"> ◆ Wildlife have many important social roles including: <ul style="list-style-type: none"> ● nutrition ● cultural practices (medicine, adornments, legend, symbols and spirits) ● education and scientific study ◆ Wildlife health may also impact human health through the transfer of zoonotic pathogens. 	<ul style="list-style-type: none"> ◆ Economic roles of wildlife include non-consumptive (viewing, photography) and consumptive (hunting, trapping, game farming, fishing etc.) activities. Canadians spent nearly 5 billion dollars on wildlife-related recreation in 1996. ◆ Wildlife health may also impact the livestock trade through transfer of pathogenic agents. ◆ Transfer of disease pathogens from captive farmed wildlife to free-ranging wildlife populations. ◆ Health issues may alter and increase the resources and time required for species at risk recovery. They, therefore have a large role in determining the costs and likelihood of success.
Examples	<ul style="list-style-type: none"> ◆ Lyme disease emerged as a result of habitat reforestation in densely populated human areas which led to the altered ecology of white-footed mice (<i>Peromyscus leucopus</i>), the principal reservoir host of the bacterial agent of Lyme disease, <i>Borrelia burgdorferi</i> and white-tailed deer (<i>Odocoileus virginianus</i>), an important maintenance host of the disease's tick vector, <i>Ixodes scapularis</i>. ◆ The 'butterfly effect': The introduction of myxoma virus into rabbit populations in Britain is thought to be the ultimate cause of extinction of the large blue butterfly (<i>Maculina arion</i>) due a series of changes in community structures. 	<ul style="list-style-type: none"> ◆ In North America, sylvatic rabies is maintained in raccoons, red and grey foxes, coyotes, bats and skunks. ◆ Increased human exposure to persistent organic pollutants from wildlife in Inuit communities who rely on subsistence hunting of animals near the top of the food chain, where toxins accumulate. 	<ul style="list-style-type: none"> ◆ Brucellosis and tuberculosis in wood bison are excellent examples of diseases that occur in wildlife that have serious economic implications for livestock trade. ◆ Bullfrog (<i>Rana catesbeiana</i>) farming and spread of chytridiomycosis into wild amphibian populations worldwide. ◆ Chronic wasting disease in deer and elk farming and subsequent spread into free-ranging wildlife populations. ◆ Avian influenza in waterfowl can be spread to domestic poultry species. ◆ Good nutrition in marmots increases fecundity and reduces the interval between reproductive episodes. This speeds up production of young for release and therefore may reduce the costs associated with the recovery program.
References	Bengis et al. 2002; Chardonnet et al. 2002; Munson and Karesh 2002; Ostfeld and Keesing 2000; Scott 1988; Tabor 2002; Van Oostdam et al. 2004		

How then, considering these broad ecological, social and economic roles of wildlife, can we define wildlife health? In order to encompass these roles, we propose the following definition. A healthy wildlife population:

1. has 'resources for everyday living' such as water, food, and an appropriate amount and type of habitat
2. is free from significant effects from health risk factors such as toxins, biological pathogens, genetic limitations, and excessive predator/hunting pressures
3. is able to meet ecological (population dynamics and function) and ecological/social (traditional use, tourism, hunting) expectations.

2.b. How does health impact wildlife population dynamics?

Population dynamics are regulated by four basic biological processes: birth, death, immigration and emigration (Figure 1). These processes occur simultaneously but are independent of one another (Scott and Smith 1994).

Figure 1. Population dynamics.



Health can be viewed as all that is necessary for everyday living. However, health considerations in wildlife have historically been limited to diseases resulting in death or obvious physical disability (Table 2). Because disease may impact all of the four basic biological processes that regulate population dynamics (Figure 1), the effects of disease on wildlife populations can be both obvious (i.e. mass mortality events such as distemper in Serengeti lions or black-footed ferrets) and subtle (i.e. decreased fledgling success in red grouse with higher parasite loads). The impact of DDT on certain raptors and piscivorous bird populations is a classic example where a disease that rarely resulted in overt clinical signs or death caused a dramatic decrease in recruitment due to egg thinning and breakage (Wobeser 1994). Also, certain disease agents have been shown to influence the distribution of wildlife populations. For example, the meningeal worm (*Parelaphostrongylus tenuis*), a nematode of white-tailed deer, influences the distribution of caribou, moose and deer in North America (Scott 1998) by causing severe dysfunction or death in these accidental hosts. This example emphasizes the importance of understanding the population biology of parasite species within the range of species at risk. Table 3 provides a summary of examples of impacts disease can have on wildlife population dynamics.

Table 2. Examples of disease events with dramatic mortality effects on species at risk recovery strategies.

Family	Species	Disease event	References
Artiodactylae	Père David's deer (<i>Elaphurus davidianus</i>), Indian guar (<i>Bos gaurus</i>), banteng (<i>Bos javanicus</i>), Arabian oryx (<i>Oryx leucoryx</i>)	Malignant catarrhal fever	Reid et al. 1987
Canidae	Wild dogs (<i>Lycaon pictus</i>)	Rabies outbreak in Masai Mara, Kenya	Kat et al. 1996, Gascoyne et al. 1993
Felidae	Lions (<i>Panthera leo</i>), spotted hyaenas (<i>Crocuta crocuta</i>)	Distemper virus outbreak in the Serengeti	Cleaveland et al. 2000
	Cheetah (<i>Acinonyx jubatus</i>)	Feline Infectious peritonitis	Evermann et al. 1988.
Mustelae	Black-footed ferrets (<i>Mustela nigripes</i>)	Canine Distemper virus	Thorne and Williams 1988
Cathartidae	California condor (<i>Gymnogyps californianus</i>)	Lead (and antifreeze) poisoning	Stringfield 1998
	Oriental white-backed vulture (<i>Gyps bengalensis</i>), long-billed vulture (<i>G. indicus</i>), slender-billed vulture (<i>G. tenuirostris</i>)	Diclofenac poisoning on the Indian subcontinent	Schultz et al. 2004, Taggart et al. 2007, Green et al. 2004
Gruidae	Whooping crane (<i>Grus Americana</i>)	Eastern Equine Encephalitis	Dein et al. 1986
Class – Amphibia	Amphibian species	Fungal infection - worldwide (<i>Batrachochytrium dendrobatidis</i>)	Lips et al. 2006, Pounds et al. 2006,

Table 3. Examples of health impacts on wildlife population dynamics.

Processes of population regulation	Examples of diseases that affect population dynamics	Impact of disease on population regulation	References
Foraging Behaviour	•Nasal bots in reindeer in Norway	Influenced foraging patterns	Scott (1988)
Reproductive Behaviour	•Mice and nematode (<i>Trichinella spiralis</i>):	Altered ability to rear young: litter survival significantly reduced when mother infected	Scott (1988)
	•Sage grouse and malaria	Mate selection and timing: infected males attended lek less often, bred later in the season and mated less frequently with 'less fit' females	Wobeser (1994) Hamilton and Zuk (1982)
	•Passerines and blood infection:	significant association between infection and striking display ('brightness' and male song)	
Social Behaviour	•Mice and nematode (<i>Heligmosomoides polygyrus</i>):	Dominance: infected mice less likely to become dominant at levels that do not affect weight gain	Freeland (1981)
Community structure	•Myxoma virus in England:	Direct effect: rabbit populations declined Indirect effects: increased initial vole population, decreased sand lizards, fox, buzzard and stoat populations, extinction of large blue butterfly (<i>Maculina arion</i>)	Scott (1998)
Distribution	•Caribou and moose and meningeal helminth parasite (<i>Parelaphostrongylus tenuis</i>)	Altered dispersal and movement patterns due to high mortality rates in areas where the white-tailed deer is a carrier species (impacts on feeding and increased risk of predation)	McCallum and Dobson (1995)
	•Hawaiian avifauna and malaria:	Birds susceptible to malaria are largely found at altitudes above where the mosquito vector thrives	Scott (1988)

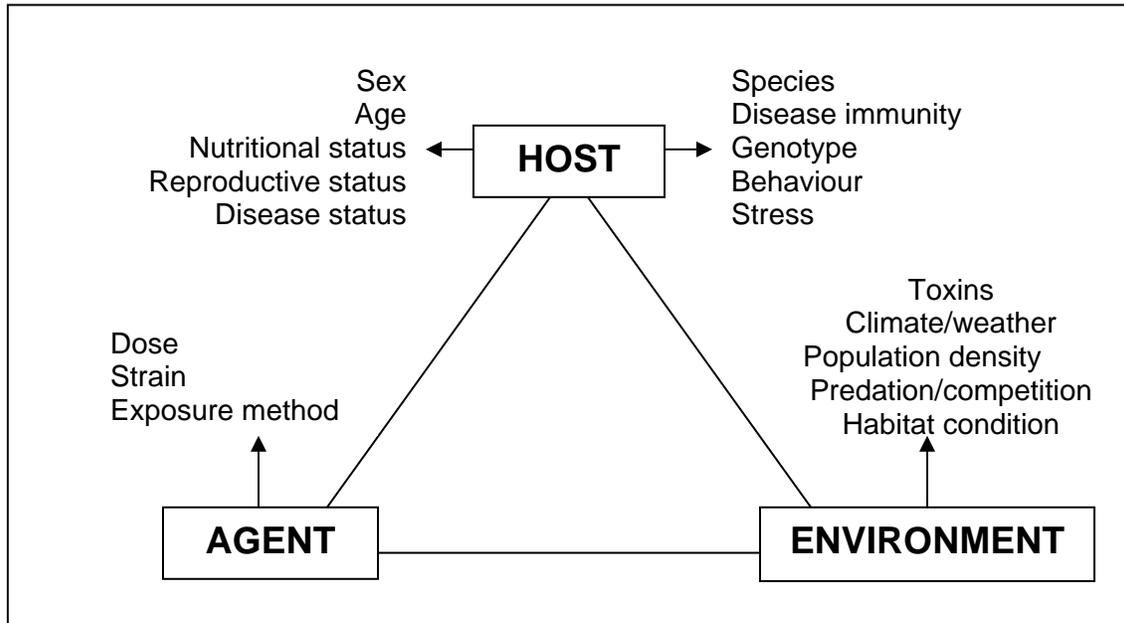
Processes of population regulation	Examples of diseases that affect population dynamics	Impact of disease on population regulation	References
	•Lizard and malaria	Decreased running stamina	
Fitness	•Heavy, dominant reindeer more heavily infected with gastrointestinal nematodes	May alter competitive fitness (examples of increased and decreased fitness with higher 'parasite' levels)	Scott (1988)
Fecundity	•American Kestrel and nematode (<i>Trichinella pseudospiralis</i>): •Sheep infected with liver fluke (<i>Fasciola hepatica</i>) •Elk and sheep and brucellosis:	Delayed time to first egg being laid, lower number of eggs, and reduced percentage of hatched eggs Delayed age of sexual maturity Increased rate of abortion	Scott (1988)
Genetics	•Cheetah and feline infectious peritonitis	Populations found to have extremely low genetic variation compared to other mammalian species (10 to 100 times lower), likely due to severe population bottleneck. Genetic variability influences disease transmission, susceptibility and the ability of an infection to establish itself in a population	O'Brien et al. (1985); Scott (1988); Springbett et al. (2003)
Population structure	•Feral cats and feline panleucopenia (feline distemper):	Pathogenic to kittens but rarely to adults therefore the age-structure of the population is changed	Scott (1988)
Predation	•Caribou	Increased susceptibility to predation related to 'parasite' loads	Scott (1988)
Stress	•Fish	Increased water temperature decreases natural resistance in fish and predisposes them to increased parasitism. Stress, expressed behaviourally or physiologically, may have effects at the individual, population or ecosystem level.	Esch (1975)

Important determinants of health

By the definition provided above, health risks to wildlife are not limited to biological agents (bacteria, viruses, parasites, fungi). They include environmental factors (i.e. toxins, climate, habitat, population density) and host factors (i.e. disease immunity, nutrition, stress). The classical triad represented in Figure 2 provides an overview of these interrelated health risk factors. A population or host's response to these health risks may range from overt disease or death to subtler effects such as decreased fecundity or altered behaviour.

Although health risks to wildlife are many and varied, disease is a particularly important determinant of health not only for its ability to cause dramatic mortalities in wildlife populations but also for its population regulating impacts (Section 2.b). By disease we are referring not only to infection with a bacterium, virus or parasite but any physiological or psychological dysfunction (Last 2001). Due to the importance of disease as a determinant of wildlife population health, it is the focus of this document.

Figure 2. Classical triad representing the interrelationship between host, agent and environment.



3.a. Disease transmission in wildlife populations

Infectious agents of disease can be transmitted from infected to susceptible animals either through direct or indirect transmission (Box 2).

Transmission of infectious agents can also be described in terms of the transmission between (vertical transmission) or within (horizontal transmission) an age cohort (Box 2).

Infection does not necessarily imply disease. A virus, bacterium or parasite can successfully invade and become established in a host animal and not cause disease. Only if an infectious agent is detected and affects the form or function of the host do we consider the animal to be diseased. However, not all diseased animals show overt clinical signs of disease; some will have changes that are only detected with blood or tissue tests. Even animals that are infected but do not show any signs of disease can still play a role in transmission and propagation of infectious agents in the population and are thus considered 'carrier' animals. In addition, an infectious disease may be present in a wildlife population and not negatively impact the health of the population. The individual animal may not be healthy but the population as a whole is meeting all of its expectations.

3.b. Disease propagation in wildlife populations

The establishment of a disease in a new population requires two main elements. The first is that there are sufficient susceptible animals to allow the pathogen to be transmitted and propagated between animals. The second requirement is that susceptible animals are exposed in a manner and with an amount of the agent that allows infection and subsequent disease to be established. Herd immunity (Box 2) may limit the ability of an agent to establish itself in a population. The proportion of the population required to be immune (i.e. not susceptible) to prevent disease propagation varies according to the agent, the distribution of immune and susceptible animals, and transmission characteristics of the agent. The effect of these two elements (the number of susceptible animals and the level of exposure) can be summarized using the Reed-Frost model to calculate the number of cases of an infectious disease that could be expected over a given time period in a closed, freely mixing population (Box 2) (Martin et al. 1987).

Box 2: Transmission terminology

Direct transmission: immediate transfer of infectious agents between infected and susceptible animals through direct contact (touching, biting, sexual intercourse).

Indirect transmission: transfer of infectious agents between infected and susceptible animals by means of :

- i) airborne droplets
- ii) vectors: invertebrates carry infectious agents between vertebrates
- iii) vehicles: infectious agents carried on inanimate objects (i.e. equipment, food, water, soil)

Horizontal transmission: movement of infectious agents between animals of similar age group or generation.

Vertical transmission: transmission from one generation to the next: prenatally, during delivery or in the postnatal period through the mother's milk (i.e. from parent to offspring).

Basic reproductive ratio (R_0): the expected number of secondary infections produced by the introduction of an infected individual, during the course of its infectious period, into an otherwise completely susceptible population. $R_0 =$ number of contacts per unit of time per individual \times probability of transmitting the disease per contact \times mean duration of infectious period.

Herd immunity: Resistance of a population to invasion and spread of an infectious agent, based on the agent-specific immunity of a high proportion of the population.

Reed-Frost model: mathematical model of infectious disease transmission and herd immunity.

$$C_{t+1} = S_t (1 - Q^C_t)$$

Where:

C = the number of cases

S = the number of susceptible

Q = the probability of no adequate contact

t = time counter

(Last, 2001; Martin et al. 1987; Scott and Smith 1994)

Another method to explore the ability of an agent to spread through a population is the basic reproductive ratio (R_0); where R_0 is a measure of the average number of resultant infections produced by the introduction of an infected individual, during the course of its infectious period, into a completely susceptible population. R_0 is determined by the number of animals exposed to the infected individual, the probability of transmission, and the duration of the infectious period. This measure provides a threshold level at which an infectious disease will spread through a susceptible population once the infectious agent is introduced (if $R_0 < 1$ than the disease dies out, if $R_0 > 1$ than the disease spreads in the population). The basic reproductive ratio for each environment and host community varies depending on factors such as population density, mortality of animals of reproductive age, animal interactions, and habitat availability and quality (i.e. likelihood of exposure is dependent on the density on feeding grounds, host susceptibility and duration of infectiousness are dependent on nutritional status) (Scott and Smith 1994).

Health management of species at risk populations

Several definitions of management exist. Some examples include "...the action of measuring a quantity on a regular basis and of adjusting some initial plan" and "...the actions taken to reach one's intended goal"⁴. From these definitions we can identify three critical components of health management: 1) assessment of health, 2) identification of goals for health recovery, and 3) development of a plan to meet the identified objectives. In section 4.a. of this report we discuss an approach to health assessment. In parts 4.b. and 4.c. we discuss methods to assess health and identify health assessment tools. In section 4.d. we identify some of the challenges faced when trying to interpret the resulting information. Finally, in section 4.e. we discuss the importance of setting goals and how to incorporate health in the development of a targeted health management plan for species at risk populations.

4.a. An approach to health assessment

There are number of risk assessment models available for evaluating and managing disease risks in wildlife and domestic livestock. Example models are available from the Canadian Food Inspection Agency (CFIA)⁵, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)⁶, and the World Organisation for Animal Health (OIE)⁷. These models often focus on specific disease agents and animal movement events and usually require very detailed information about the prevalence and distribution of these agents in the species of concern. Here we present a more generalized assessment model for evaluating population health that allows for health monitoring and mitigation actions to be tailored to a population's overall level of risk. The nature and magnitude of recovery initiatives depend on the current status of the species at risk population and the nature of identified health hazards. We have identified three action modes for management and recovery of species at risk (Figure 3).

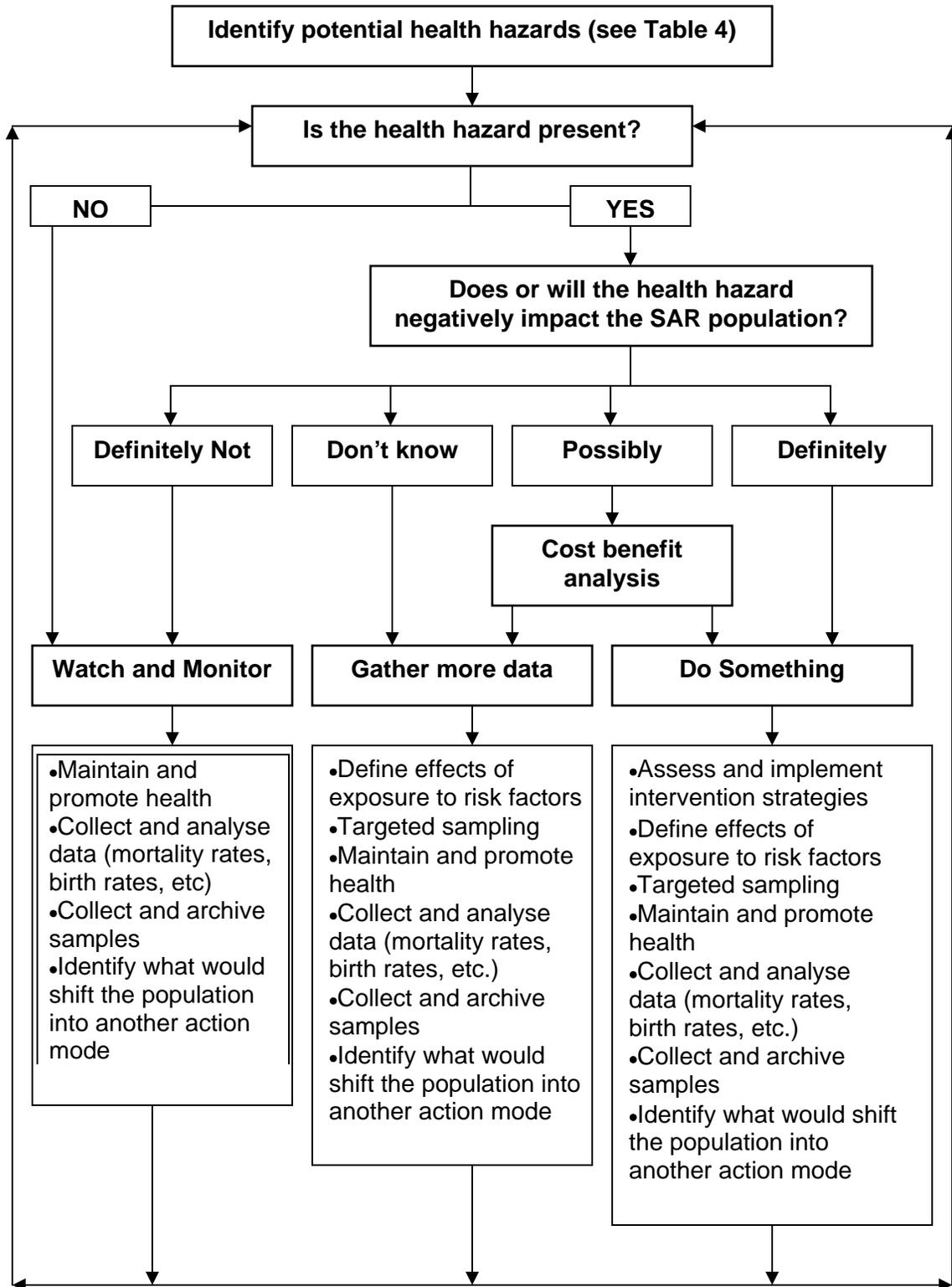
⁴ <http://en.wikipedia.org/wiki/Management>

⁵ <http://www.inspection.gc.ca/english/sci/ahra/rianfrwk/rianfrwke.shtml>

⁶ <http://www.omafra.gov.on.ca/english/research/risk/frameworks/as2.html>

⁷ *Scientific and Technical Review*, Vol. 14 (4), December 1995

Figure 3. Health assessment for species at risk populations.



The first step in assessing the health of species at risk is to identify real or potential health risk factors for the population of concern (Table 4). In order to do this, one must consider the population of interest and the current management strategies in place. In addition, one must consider what is known about the potential hazards (where they are, what species are at risk, is the hazard infectious/how is it transmitted, how does it affect the health of the host and the population, etc.). Before potential health hazards can be identified and their potential for impact on species at risk populations assessed, the specific population of interest needs to be defined. For several species at risk, both wild and captive populations exist and the population of interest may be one or the other or both. Although the four basic biological processes influencing population dynamics (birth, death, immigration and emigration) are the same for all populations, the particular areas of concern differ. In wild populations we are concerned about reduced reproduction and fecundity, increased mortality and changes in animal movement. In captive populations we have the same concerns as for wild population but we also need to consider reduction in survival both in captivity and in those animals that are reintroduced to the wild as well as factors that may inhibit our ability to reintroduce a population into the wild.

Table 4. Some potential health hazards and their impacts on species at risk populations.

Health Risk Factors:	Potential impact
Translocation or captive breeding	Increased susceptibility to disease or injury from stress, nutritional deficiency, genetic intermixing etc. Increased potential for disease transmission and propagation due to increased density or exposure to novel pathogens
Inbreeding or genetic bottleneck	Increased disease susceptibility
Association with domestic livestock	Potential for disease transmission (either to or from wildlife)
History of disease issues in species or family	Known susceptibility to an infectious agent or environmental contaminant
Some habitat issues that put population health at risk:	
a. Insufficient quantity or quality of food	Poor nutrition leads to increased disease susceptibility, lower fitness, and reproductive performance
b. Increased density due to diminished habitat availability	Greater likelihood of disease transmission, increased predation, etc.
c. Distribution (e.g. out of historic range, new species sharing range)	Potential for exposure to novel pathogens for which the species of concern has no immunity
d. Exposure to pollutants, habitat disturbance or human development (i.e. roads, industry...).	Direct impact: overt disease from toxicity Indirect impact: increased susceptibility to disease or predation, altered behaviour, reproduction, stress, etc.

Once potential hazards have been identified, their impacts on the species at risk population dynamics can be evaluated. However, identification of important health risks and information about their potential impact on wildlife populations can be challenging to find. Wildlife biologists, managers and planners should consider several sources from which to gather information. These include:

1. *Review of the literature* (disease reports for species at risk or similar species)
The scientific literature includes disease reports from other jurisdictions and other countries that have dealt with or identified health risks in native populations. In addition, sampling and clinical trials performed in captive or sympatric populations can provide insight into which health risks may prove important in species at risk. Finally, results obtained from case studies and trials performed on other wildlife species, domestic animals or even humans can generate hypotheses about the importance of and threats associated with certain health risk factors.
2. *Personal communications*
The importance of communication cannot be over emphasized. A framework for good communication between and within provincial ministries, among provinces, across international borders and between industry, governments and other interested parties is essential. Others often have insight into and experience with important health hazards for species at risk. Much can be gained from what others have done and experienced and this information is not always published in the scientific literature.
3. *Past experience*
Always consider what has been seen or experienced in the past. What has previously affected a wildlife population in the past can recur and what has affected one population can affect another.
4. *Analysis of surveillance data*
Surveillance implies more than simply the collection of data – analysis and action are essential components of effective surveillance. Data on population parameters may assist managers and planners to calculate mortality rates (either cause specific or overall) and track trends over time and in different geographic locations. With this information, changes in population dynamics can be detected early on and control or intervention strategies can be implemented in a timely fashion. Early intervention may provide the best opportunity for successful recovery.
5. *Review of archived samples for potential testing*
Many of the diseases that affect wildlife populations are either new or have not been seen in some time. Thus we can consider many of the health risks to wildlife as either emerging or re-emerging. Because of the novelty of these diseases, we often do not know what tests to run and consequently samples are not tested for certain chemicals or pathogens. In addition, analysis techniques are continually changing thus improving our ability to detect disease. While a disease may have been present in a particular population for generations, we only now are beginning to investigate its effects on the affected population. As the tests become more sensitive and specific, are validated in wildlife populations, and as our knowledge and understanding of disease grows, archived samples can be accessed and tested to see whether the disease is truly new or in fact has been there for some time and we simply didn't have the ability to test for it until now.

Once important potential health hazards have been identified, one must then determine whether or not they are present in the population of interest and the degree of threat they pose. The level of threat from health hazards to a population influences the amount and type of health mitigation strategies that are required. If there are no obvious health risks to a species at risk population then no action is required. The population will however require ongoing monitoring (Figure 3: Watch and Monitor). Populations where health risk factors are present and are clearly a threat to the population (based on good quality evidence) without a doubt require that action be taken quickly if that population is to recover (Figure 3: Do Something). In other words, some types of interventions (e.g. captive breeding, translocation, immunization) are required if the probability and magnitude of the effect on the population is high.

The situation is less certain when we either don't have the knowledge to determine whether a health hazard is present or is an important threat to the population, or when it seems reasonable to assume that the hazard will have an impact but the level of impact is as yet unclear. If there is a paucity of scientific research about the species at risk (habitat, natural behaviour, range, etc.) or about potential health hazards (pathogens, environmental contaminants, habitat destruction, etc.) then more information must be gathered before any action can be taken. If, however, there is some evidence of risk to health but the impact or effect is uncertain then a cost-benefit analysis should be performed (Aubert 1999). Things to consider include:

- 1 - population status (where on the SAR continuum is the population of interest?)
- 2 - nature of the potential hazard (does it act quickly, will the impact be severe and irreversible?)
- 3 - the cost of the required intervention

The responses to these considerations will determine whether action will be taken or whether there is time to gather more information before the decision to act is made.

4.b. Health assessment methods

i) Basic epidemiology

To describe a disease in a species at risk population we need to consider all possible means of effect. These include what species and which individuals within the population may be most affected, how the population will be affected and in what regions and/or habitat types and season the impact will be greatest. In basic terms one needs to identify the "W5" of the disease: who, what, where, when and why (Table 5).

Table 5. The "W5" of wildlife health management.

Who	What	Where	When	Why
<ul style="list-style-type: none"> •species •age •sex •sub-population 	<ul style="list-style-type: none"> •organ systems •habitat 	<ul style="list-style-type: none"> •habitat •distribution 	<ul style="list-style-type: none"> •season •temporal trends 	This is where we need to generate hypotheses

To further characterise the impact of disease on the population, rates of disease need to be calculated. There are two measures of disease rates: incidence and prevalence (Box

3). For many species at risk however, we don't know either the population at risk or their distribution. Consequently it is very difficult to accurately calculate a rate of disease.

Box 3: Rates of disease:

Incidence (I) - new cases of a disease in a given population over a specified period of time

$$I = \frac{\text{number of new cases over a given time period}}{\text{population at risk over a given time period}}$$

Prevalence (P) – total number of cases of a disease in a given population at a single point in time

$$P = \frac{\text{number of total cases at a given time}}{\text{population at risk at a given time}}$$

ii) How do we know if an agent or risk factor is CAUSING a health impact?

Our understanding of disease and ability to detect it is continually evolving. When a declining population is noted, our first step usually is to go looking for a cause – a pathogen, a toxin or some other agent. If we identify an agent from the diseased or dead animals then our instinct is to label it as the cause of the population decline. However, establishing a causal relationship is not so straightforward. How do we know that the identified agent has not always been there and is simply a commensal parasite/agent of that species? If it has always been there – has it changed or has something else affected the species at risk to make them more susceptible to that agent? To establish whether a specific agent is causing a health impact there are several criteria that need to be met (Box 4).

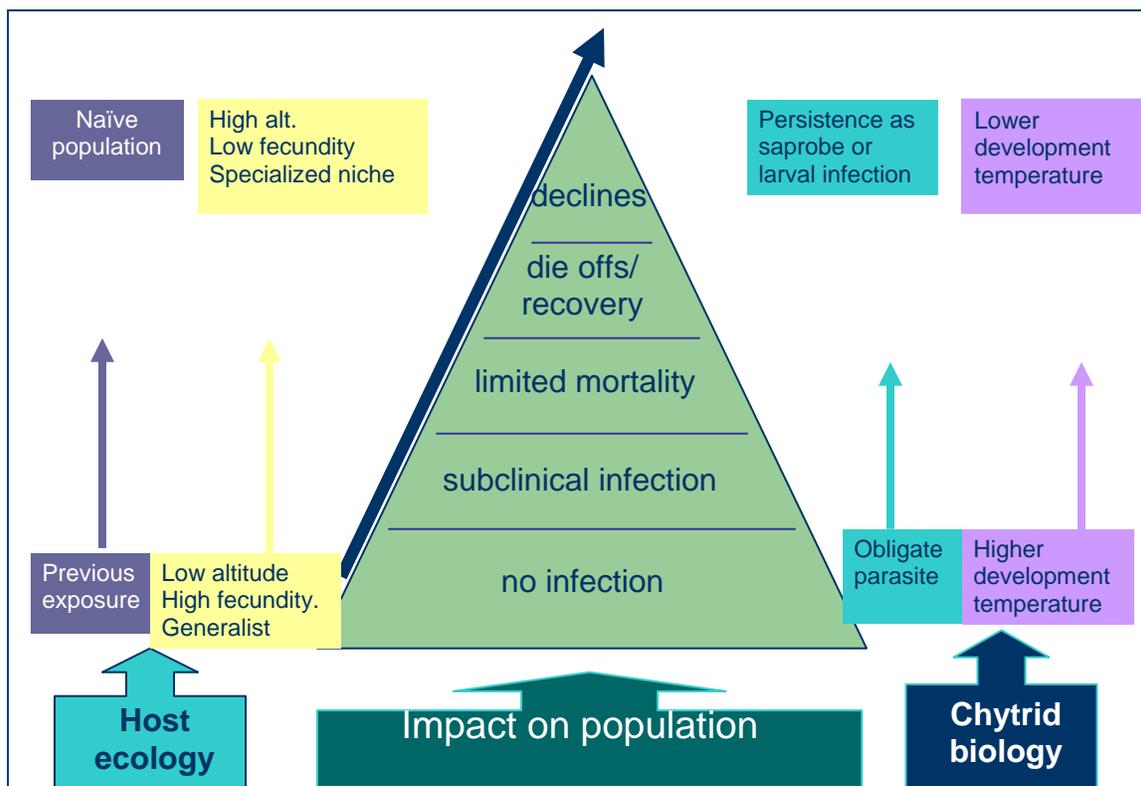
Box 4: Evan's Postulates of Causation (Adapted from Last, 2001)

- Rates (prevalence and incidence) of disease are higher in populations exposed to the health hazard than those that are not
- Exposure to the health hazard is more frequent in the population with the disease than those without disease
- Disease should follow exposure in time
- High exposure results in more severe disease, low exposure should result in less severe disease
- Experimentally exposed animals are more likely to develop the disease than unexposed controls
- Reducing exposure should decrease rate of disease
- Improving host response to exposure should decrease or eliminate disease
- All relationships and findings should make biological and common sense

Establishing causation can present many challenges. As an example, consider the Northern Leopard Frog (*Rana pipiens*) and chytridiomycosis. *Batrachochytrium dendrobatidis*, more commonly referred to as chytrid, is a fungus that was first

recognized in Australia in 1993. Subsequent research has shown that the fungus has been present in Australia since at least 1978. Since its discovery, chytrid has been isolated from Africa, the Americas, Europe, New Zealand and Oceania. Although the discovery of chytrid correlates with the decline of many frog populations, there is no clear evidence to show that it is the cause of these declines. What further confuses the issue is that some populations appear to be immune to the infection and others are highly susceptible. Furthermore, little is known about the pathogen, its life cycle, mode of transmission, and mechanism of disease. It is possible that the fungus has been present in the environment for years but has become more virulent or the frog populations have become more susceptible – either through habitat destruction, climate change or other infectious agents (Daszak 2003). Figure 4 demonstrates the range of host and agent factors that are thought to influence the impact that the chytrid fungus has on amphibian populations. In B.C., the Northern Leopard frog population has dropped steeply – with the remaining frog population isolated to a small area near Creston, B.C. Chytrid has been isolated from the population but its causal role in the population decline has not been established. Problems with chytrid infections are further complicated because, once established, it is nearly impossible to remove from the environment. Clearly something needs to be done to recover this population but until we gather more data the only recourse appears to be to breed them in captivity. The recovery team has opted for captive head-starting; the frogs breed in captivity and then the juveniles are released back into their natural environment.

Figure 4. The impact of chytridiomycosis on amphibian populations (Daszak et al. 2003).



4.c. Health Assessment Tools

There are a variety of tools available to assess the health of domestic animals and, in general, the same tools can also be used to assess the health of wildlife populations. Although the same tools are available, in many circumstances the tests have not been validated in many wildlife species. Consequently, there are important limitations to be aware of when interpreting test results. This section outlines a range of health assessment tools that can be applied to both live (and dead (Table 7) animals.

Table 6: Measurable health parameters in live animals⁸.

Parameter	What can it tell you?	What are its limitations?	Skill level ⁹	Equipment ¹⁰	References
Physical observation or examination	<ul style="list-style-type: none"> At a distance: abnormalities in behaviour, physical condition, gait, posture, attitude, symmetry, coat/ feathers. 	<ul style="list-style-type: none"> Limited to opportunities when animals can be observed closely or handled (tagging, radio collaring, translocation, captive breeding etc.). 	Novice to expert depending on level of detail	<ul style="list-style-type: none"> Basic observation or exam: camera Detailed exam: thermometer, 	

⁸ Refer to the CCAC guidelines, 2003

⁹ Skill level: novice: no experience required, intermediate: some training required, expert: expertise required

¹⁰ The equipment required and sampling techniques are constantly changing, consequently it is best to contact lab that will be doing the analysis for these details.

Parameter	What can it tell you?	What are its limitations?	Skill level ⁹	Equipment ¹⁰	References
	<ul style="list-style-type: none"> •<i>Up close:</i> clinical signs of gross abnormalities in some major systems (gastrointestinal, respiratory, cardiovascular, genitourinary, musculoskeletal, skin, nervous and lymph systems) 	<ul style="list-style-type: none"> •Quantification of findings are difficult as rating systems are subjective 		stethoscope, pen light	
Fecal examination: <i>Parasitology / microbiology:</i>	<ul style="list-style-type: none"> • Parasite/pathogen burden and identification of species 	<ul style="list-style-type: none"> •Not all parasites and pathogens are shed at all times 	Novice	Sealable bag	Fowler and Miller 2003; Sloss et al. 1994
Fecal examination: <i>DNA analysis</i>	<ul style="list-style-type: none"> •Can isolate mitochondrial DNA (mtDNA), microsatellite DNA, and single-copy nuclear DNA (scnDNA) from scat. •MtDNA can confirm species, geographic origins of populations and assess rates of evolution. •scnDNA can establish gender •microsatellite DNA can establish individual identity, geographic distribution and genetic relatedness 	<ul style="list-style-type: none"> •Usefulness of test depends on: a) the length of DNA extracted from feces b) confirmation that DNA in feces is identical to that obtained from blood or hair of same animal, c) elimination of sample contamination (hair, blood), d) prevention of sample degradation, and e) removal of dietary inhibitors. 	Novice	Sterile tongue depressor, small vial	Wasser et al. 1997 and 2002
Fecal examination: <i>Fecal hormones</i>	<ul style="list-style-type: none"> •Non-invasive measure of physiological stress (adrenal hormones) or endocrine disruption (gonadal hormones). 	<ul style="list-style-type: none"> •Hormones are also excreted in urine; some animals may urinate on feces which elevates level of hormone. •Fecal hormone levels are affected by diet (freeze-drying samples helps address this). •Not validated for all species and baseline levels unknown for many species 	Novice	Sealable bag, freezer (-20°C)	Wasser et al. 2002 Wells et al. 2004
Blood examination: <i>Hematology</i>	<ul style="list-style-type: none"> •Accurate, practical assessment of red blood cells and hydration status •Indication of presence and duration of infection 	<ul style="list-style-type: none"> • Normal ranges unknown for many species •Animal restraint is needed (physical or chemical restraint) 	<ul style="list-style-type: none"> •Novice for blood sample from toenail or ear •Intermediate for direct venous sample 	Blood collection tubes, needles, syringes, cooler and cold packs for sample storage, clipper for collection from toenail or ear	Fowler and Miller 2003
Blood examination: <i>Serum Biochemistry</i>	<ul style="list-style-type: none"> •Provides a means of evaluating organ function and stress •Can confirm haematological findings (infection, hydration) 	<ul style="list-style-type: none"> • Normal ranges unknown for many species •Animal restraint is needed (physical or chemical restraint) •Depending on the number of tests to be 	<ul style="list-style-type: none"> •Novice for blood sample from toenail or ear •Intermediate for direct venous sample 	Blood collection tubes, needles, syringes, cooler and cold packs for sample	Fowler and Miller 2003

Parameter	What can it tell you?	What are its limitations?	Skill level ⁹	Equipment ¹⁰	References
		run, a larger volume of blood than can be collected by ear or toenail clip may be needed		storage, clip/blade for collection from toenail or ear	
Blood examination: <i>Serology</i>	<ul style="list-style-type: none"> •Level of antibodies can confirm the presence of infection •Evaluate whether the host was previously exposed to an infectious agent through natural infection or vaccination and has developed immunity to the agent 	<ul style="list-style-type: none"> •Test may cross-react with a shared antibody from another infection •Antibodies may be as a result of transfer from mother to young (not from infection) •Poor test specificity resulting in false positive results (see test section) 	Intermediate	Blood collection tubes, needles, syringes, cooler and cold packs for sample storage	B.C. Animal Health Centre WCVM – Prairie Diagnostic Centre
Other tissues: <i>Hair/feather</i>	<ul style="list-style-type: none"> •DNA/genetic analysis to identify species and individual characteristics (age, sex...) •Presence or absence of heavy metals or other toxins •Diet history via stable isotopes 	<ul style="list-style-type: none"> •Normal ranges unknown for many species •Test characteristics (sensitivity and specificity) for the most part unknown 	Novice	Bag for collection and holding of samples, sterile gloves and forceps for collection	Tieszen and Boutton 1989
Other tissues: <i>Biopsy (skin, muscle...)</i>	<ul style="list-style-type: none"> •DNA/genetic analysis to identify species and individual characteristics (age, sex...) •Presence or absence of heavy metals or other toxins •Diet history via stable isotopes •Presence or absence of parasites 	<ul style="list-style-type: none"> •Normal ranges unknown for many species •Test characteristics (sensitivity and specificity) for the most part unknown 	Advanced	Requires capture of individual animal, sedation or full anaesthesia, administration of pain control medications and surgical skills	WCVM; B.C. Animal Health Centre; Tieszen and Boutton 1989

Table 7. Measurable health parameters in dead animals.

Parameter	What can it tell you?	What are its limitations?	Skill level ¹¹	Equipment ¹²	References
Fecal examination: <i>Parasitology / microbiology:</i>	<ul style="list-style-type: none"> • Parasite/pathogen burden and identification of species 	<ul style="list-style-type: none"> •Not all parasites and pathogens are shed at all times 	Novice	Sealable bag	Fowler and Miller 2003; Sloss et al. 1994
Fecal examination: <i>DNA analysis</i>	<ul style="list-style-type: none"> •Can isolate mitochondrial DNA (mtDNA), microsatellite DNA, and single-copy nuclear DNA (scnDNA) from scat. •MtDNA can confirm species, geographic origins of populations and assess rates of evolution. •scnDNA can establish gender 	<ul style="list-style-type: none"> •Usefulness of test depends on: a) the length of DNA extracted from feces b) confirmation that DNA in feces is identical to that obtained from blood or hair of same animal, c) elimination of sample contamination (hair, blood), d) prevention of sample degradation, and e) removal of dietary 	Novice	Sterile tongue depressor, small vial	Wasser et al. 1997 and 2002

¹¹ Skill level: novice: no experience required, intermediate: some training required, expert: expertise required

¹² The equipment required and sampling techniques are constantly changing, consequently it is best to contact lab that will be doing the analysis for these details.

Parameter	What can it tell you?	What are its limitations?	Skill level ¹¹	Equipment ¹²	References
	<ul style="list-style-type: none"> •microsatellite DNA can establish individual identity, geographic distribution and genetic relatedness 	<ul style="list-style-type: none"> inhibitors. 			
Fecal examination: <i>Fecal hormones</i>	<ul style="list-style-type: none"> •Non-invasive measure of physiological stress (adrenal hormones) or endocrine disruption (gonadal hormones). 	<ul style="list-style-type: none"> •Hormones are also excreted in urine; some animals may urinate on feces, which elevates level of hormone. •Fecal hormone levels are affected by diet (freeze-drying samples helps address this). •Not validated for all species and baseline levels unknown for many species 	Novice	Sealable bag, freezer (-20°C)	Wasser et al. 2002 Wells et al. 2004
Blood examination ¹³ : <i>Serum Biochemistry</i>	<ul style="list-style-type: none"> •Provides a means of evaluating organ function and stress •Can confirm haematological findings (infection, hydration) 	<ul style="list-style-type: none"> • Normal ranges unknown for many species •Good serum sample may or may not be available depending on the quality of the carcass 	Intermediate	Blood collection tubes, needles, syringes, cooler and cold packs for sample storage, filter paper	B.C. Animal Health Centre; WCVM
Blood examination: <i>Serology</i>	<ul style="list-style-type: none"> •Confirm the presence of infection •Evaluate whether the host was previously exposed to an infectious agent through natural infection or vaccination and has developed immunity to the agent 	<ul style="list-style-type: none"> • Normal ranges unknown for many species •Good serum sample may or may not be available depending on the quality of the carcass •Test may cross-react with a shared antibody from another infection •Antibodies may be present as a result of transfer from mother to young (not from infection) ◆ Poor test specificity resulting in false positive results (see test section) 	Intermediate	Blood collection tubes, needles, syringes, cooler and cold packs for sample storage, filter paper	B.C. Animal Health Centre; WCVM
Other tissues: <i>Hair/feather</i>	<ul style="list-style-type: none"> •DNA/genetic analysis to identify species and individual characteristics (age, sex...) •Presence or absence of heavy metals or other toxins 	<ul style="list-style-type: none"> •Normal ranges unknown for many species •Test characteristics (sensitivity and specificity) for the most part unknown 	Novice	Bag for collection and holding of samples, sterile gloves and forceps for collection	WCVM; B.C. Animal Health Centre
Post mortem examination: <i>Gross exam</i>	<ul style="list-style-type: none"> •Body condition, age and sex •Presence or absence of injury or disease (acute or chronic) 	<ul style="list-style-type: none"> •Quality of findings dependent on the quality of the carcass 	Intermediate to advanced	Gloves, scalpel or knife, saw, axe, scissors, scale	UC Davis wildlife health PM lab protocol; USGS protocol; CCWHC Manual,

¹³ Adequate, quality samples are unlikely if the animal has been dead for any significant period of time. However, PCR testing on filter paper sample may be done for some diseases. Unless bleeding is done at or just after death, this sampling technique is not practical for serum.

Parameter	What can it tell you?	What are its limitations?	Skill level ¹¹	Equipment ¹²	References
					Appendix A
Post mortem examination: <i>Microscopic exam</i>	<ul style="list-style-type: none"> •Level of organ function •Presence or absence of disease •presence or absence of heavy metals and other toxins 	<ul style="list-style-type: none"> •Quality of findings dependent on the quality of the carcass and conditions in the field 	Intermediate to advanced	Gloves, scalpel or knife, sample containers and formalin, cooler and cold packs	WCVM; B.C. Animal Health Centre

4.d. Challenges in health assessment of species at risk populations

Disease can have important impacts on the health of species at risk populations. However, our lack of understanding of wildlife hosts, agents, environments and many of the interactions between them make wildlife disease difficult to detect and even harder to measure (Wobeser 1994). Some of the challenges in disease detection and measurement include:

- a. Sampling methodology
 - Difficulties detecting disease (Deem et al. 2001)
 - Identifying what to sample
 - Finding and collecting appropriate samples
 - Need for live capture to acquire most useful samples
- b. Disease test characteristics
 - Efficacy and accuracy of most tests is unproven in most wildlife species (i.e. sensitivity and specificity of the test have not been determined)
- c. Limited ability to perform a thorough clinical exam on wildlife populations without disturbance. Consequently we most often have to rely on distant observations and lab trials or captive populations
- d. Obvious signs of disease may not be attributable to an specific organism; many diseases have signs (fever, diarrhea, weight loss) that do not specify the cause making it challenging to link an agent with a disease
 - Many tests have not been used or validated on wild species
 - Often uncertain of what to test for
- e. Wild animals may show more subtle signs of disease such as delayed age of sexual maturity or reduced growth and may take years of monitoring to detect.
 - Requires ongoing surveillance to detect subtle changes

i) How can we assess the value of a test?

The validity of a test can be assessed using four indices: sensitivity, specificity and positive and negative predictive values. Sensitivity is the ability of a test to detect disease; specificity is the ability of a test to rule-out disease; positive predictive value is the proportion of diseased animals among those that test positive; and negative predictive value is the proportion of non-diseased animals among those that test negative.

To measure the sensitivity and specificity of a test, it needs to be compared to a “gold standard”. The gold standard should be a perfect test, one where if the disease agent is not present the test will always be negative and if it is present will always show up positive. Gold standards generally do not exist but some come close. Unfortunately, most often in wildlife, there are no gold standards and very few approximations. Thus the sensitivity and specificity cannot be determined.

Even with a ‘perfect’ test it can be difficult to detect disease in wildlife populations. The magnitude and nature of the errors in test results are largely unknown. Challenges to disease detection include:

- a) The prevalence of disease is low
If very few animals are diseased in the population then a larger number of animals will need to be sampled to ensure either the presence or absence of disease. Different equations to determine sample size exist depending on the circumstances and objectives of wildlife managers (e.g. Martin et al. 1987). However, because population size and disease prevalence are often unknown for species at risk, sample size determinations will be only rough estimates.
- b) Timing of sample collection and testing
Some diseases can have a long incubation period and the pathogen won’t be detected by the test until there is either enough circulating pathogen or the host mounts a big enough immune response that can be measured by the test applied
- c) Differing parasite and disease burdens
A parasite may only be found in a small number of heavily infected individuals and absent in other animals. For example, *Echinococcus granulosus* in moose and *Toxocara canis* in the silver fox. “One consequence of this dispersion pattern is that examination of a small sample of the host population may suggest the absence of infection even though some animals may be heavily infected” (Scott 1988)
- d) Variable prevalence and intensity of disease
Many parasites are common in young animal and remain prevalent throughout the various life stages, whereas other parasites are only very common in young animals

In order to maximize the ability to detect disease, sampling strategies should be targeted at the sick or susceptible individuals. However, if our goal is to measure the prevalence or incidence of disease in a wildlife population then a random sample is needed. If the disease prevalence or incidence varies by age then it is important to stratify the sample by age to increase the likelihood of detecting it. The optimal sampling method to employ will depend on surveillance and management objectives and will require consultation with wildlife disease experts.

4.e. Setting goals and developing a health management plan

Assessment of the health status of species at risk is an adaptive or iterative process whereby a population's risk level must continually be monitored as health risks may change and shift the population into another category with differing health-related actions. Ongoing assessment provides wildlife biologists, managers and planners with the tools to know if, when, and what action is required and when that action needs to be adapted to meet the identified changes in species at risk status or risk factors.

Once we have assessed the health of the population at risk to the best of our ability, we can begin to incorporate those findings into a recovery and management plan. The results of the health assessment should enable wildlife managers to identify and set goals for the species at risk populations. The goals will reflect what we expect from the wildlife population in question. Expectations for a given population may include one or more of the following: reduction or elimination of disease, re-establishment of a wild population, maintenance of genetic diversity, and maintenance or improvement of economic production (hunting, fishing, tourism...). Whether it is even possible and if so how to achieve these objectives will depend on the wildlife population in question, the habitat in which they live and the nature of the health hazard that threatens or is already having an impact on the population. Nevertheless, some general suggestions of health-related actions that could be incorporated into wildlife management plans include:

- 1) Reduction or elimination of disease
 - a. Identify areas or populations at increased risk for the disease
 - b. Investigate methods to improve the immunity of the population (i.e. improvements in nutrition, reduction of stress, vaccination)
 - c. Consider if treatment of infected individuals to reduce disease and shedding and therefore shedding into the environment is possible and/or practical.
 - d. Removal of infected individuals
- 2) Re-establishment of a wild population
 - a. Select a historical and suitable habitat with low threats from predators and human influences
 - b. Habitat assessment
 - c. Literature survey of similar species
 - d. Disease screening and preventive therapy for translocated, captive or head-started animals. Quarantine principles must be considered for captive management and may be necessary prior to reintroduction.
- 3) Maintenance of genetic diversity
 - a. Measure and assess the level of genetic diversity
 - b. Captive breeding populations of adequate size and health to maximize the genetic potential
 - c. Collection of and storage of genetic material for future use
 - d. Supplementation from other subpopulations
- 4) Maintenance or improvement of economic production
 - a. Hunting and angling guidance based on data

- b. Develop and implement procedures to prevent the translocation of agents due to human activities
- c. Disease surveillance through submissions from hunters and anglers; which can provide valuable disease-related information as well as an educational component.
- d. Habitat evaluation and restoration

Unfortunately, many of the suggested plans to incorporate health into wildlife management plans can be costly, impractical, and of unknown efficacy. For instance, vaccines rarely exist for most wildlife diseases and when they do exist, they are generally made for livestock, can be difficult to administer using an effective protocol without causing severe stress on the animal, and methods of administration used are expensive and the efficacy in the species of concern is mostly unknown. Similar but more extreme concerns exist about treatment of diseased wildlife. Consequently, to remove disease from a wildlife population, depopulation or culling of sick animals is generally the only effective technique available. Early identification of potential health risk factors and plan development to mitigate the negative population impacts of the identified hazards is the most cost effective and successful approach to managing health in species at risk.

It is important to emphasize that once a recovery plan has been developed and implemented monitoring must continue. Ongoing monitoring and health assessment of species at risk is necessary to determine whether the recovery plans are having a positive impact on the species at risk populations and to identify any new or re-emerging health threats to the population in question. Any management plan must be able to be adapted as new information becomes available and evaluations of effects are reported. Our knowledge of the structure and function of wildlife species, their social structures and preferred habitats is constantly improving. Thus as new information becomes available it too must be incorporated and recovery plans adapted to reflect our new understanding of the complex host-agent-environment web. Adaptive management is critical to success.

5. Incorporating health into species at risk recovery plans in B.C.

We have selected two B.C. species at risk to demonstrate the application of the health assessment model outlined above (Figure 3).

5.a Northern Leopard Frog

Step 1: Hazard identification

From Table 4 and communications with others working with amphibians, we have identified the following as examples of health hazards in B.C. Northern Leopard Frog (NLF) populations:

- severe decline of the population is likely creating a genetic bottleneck
- isolation of chytrid fungus from B.C. frogs (known cause of declines in other species)
- habitat destruction by invasive species (plants and animals)

It is important to emphasize that this is by no means an exhaustive list but is meant to be used primarily for illustrative purposes.

Step 2: Determine presence/absence of identified health hazards in the Northern Leopard Frog habitat in B.C.

a. Population size

Population surveys of Northern Leopard Frog (NLF) show that the population is small and limited to a single site in the West Kootenay region. The small population size creates the potential for inbreeding which results in lost genetic potential and less ability for the population to respond to other threats that may influence the health of the population.

b. Chytrid fungus in B.C. frogs

Chytrid fungus has been isolated from NLF in B.C. This fungus has been shown to be an important cause of worldwide amphibian population declines.

c. Alien species

Invasive plant and animal species have already been identified in the Kootenays (both deliberate introductions to improve sport fishing in the area and by accidental introduction in the case of purple loosestrife and common carp).

Step 3: Determine potential for the identified health hazards to have a negative impact on the NLF population

a. Population size

Will a genetic bottleneck caused by low numbers of individual frogs impact the health of the NLF, both in the long and short term? It is unknown if the small population itself will negatively impact NLF health. While small numbers will reduce the population's ability to respond and react to other threats, we are unaware of studies that demonstrate the link between diminished genetic variability and amphibian health. Following the flow chart illustrated in Figure 3 this uncertainty puts this identified hazard into the "Don't know" category. More information is needed before the impact of a small population can be assessed.

b. Chytrid fungus in B.C. frogs

This infectious agent has been implicated in amphibian declines worldwide and has also been isolated from NLF in B.C. The threat posed by this pathogen is very real and likely severe: something needs to be done to reduce or minimize the impact. In other amphibian populations, chytrid infection has proved to be a challenging problem.

c. Alien species

There is still much to learn about the impact of invasive species on amphibian population health in general. However, there is some evidence that stewardship initiatives to reduce the effects of invasive species can successfully reduce the impact on native populations. Stewardship initiatives are often run by volunteers and thus the cost is relatively low. However, the potential benefit to the NLF is great and should, therefore, be continued and developed.

Step 4: Action plans

a. Population size

Action mode: "gather more data"

As more information is needed before the impact of a small population on NLF health can be assessed, continued research should explore the level of genetic variability and immunological competence in remaining populations. Biologists should also take

advantage of frog handling events to do general health assessments (body condition, signs of disease, presence of deformities etc). All dead frogs should be submitted for full post-mortem exams and tissues should be archived for future use. The recovery team needs to define a population size threshold at which further interventions must be undertaken.

b. Chytrid fungus in B.C. frogs

Action mode: “do something”

As this fungus appears to be negatively impacting NLF populations in B.C., an action plan for this aspect should include the following: 1) research on the distribution (geographic and species) of the pathogen in B.C., 2) prevalence estimates of chytrid in other relevant amphibian populations, 3) develop a management protocol that identifies and mitigates for key opportunities for exposure, and 4) if deemed appropriate develop a captive-breeding plan. While successful captive breeding programs have been developed to maintain genetic diversity (e.g. Wyoming Toad in USA), successful reintroduction has proved to be difficult due to chytrid’s persistence in the environment and subsequent re-infection of the toads upon release. Until such time as a suitable, uncontaminated site for release can be found, captive breeding may pose the only means of maintaining remaining NLF populations. A captive-breeding protocol should include effective standardized procedures for capture, hygiene, handling, husbandry, quarantine and pre-release testing procedures.

c. Alien species

Action mode: “gather more data”

Further research should explore the relationship of invasive alien species and, in particular, of amphibian species on NLF habitat and health (e.g. the bullfrog has been implicated in the spread of chytrid into other regions). The recovery team should also explore and assess alien species mitigation strategies (i.e. public education, alien species removal, habitat modification) that could improve NLF habitat and minimize opportunities for exposure to chytrid from non-native amphibian species.

5.b Woodland caribou – Southern Mountain population (Mountain Caribou)

Step 1: Hazard identification

From Table 4, the Recovery Strategy¹⁴ for Mountain Caribou, and Sifton’s (2001) disease risk assessment of Mountain Caribou we identified the following health hazards:

- low genetic variability
- limited winter food availability
- susceptibility to infectious agents (i.e. *Mycobacteria*, *Brucella*, *Besnoitia*)
- potential for translocations

Again, we emphasize that this is by no means an exhaustive list but is meant to be used primarily for illustrative purposes.

Step 2: Determine presence/absence of identified health hazards in B.C.’s Mountain Caribou

a. Low genetic variability

¹⁴ http://wlapwww.gov.bc.ca/wld/documents/mtcaribou_rcvyrstrat02.pdf

A 'markedly' low level of genetic variation has been noted in the South Purcell population of Mountain Caribou. Microsatellite DNA analyses showed that genetic heterozygosity ranged between 52.7% in the South Purcell population up to 82.6 % in the Chase population.

b. Limited winter food availability

There are reports of extreme winter weather events limiting winter arboreal lichen availability for Mountain Caribou. Climate change may alter forest structure and function leading to a shift in vegetation available for caribou to browse.

c. Susceptibility to infectious agents

Caribou are potentially susceptible to a wide range of infectious agents including but not limited to tuberculosis, brucellosis, paratuberculosis (Johne's disease), and besnoitiosis (Nation et al. 1999; Glover et al. 1990; Williams et al. 1983).

d. Potential for translocation events

Mountain caribou have been translocated on a number of occasions in and out of B.C. to augment diminishing populations. The recovery team has explored the potential for instituting a captive breeding program as an alternative to translocation as many potential source populations are not increasing in size; removing animals may, therefore, threaten these more stable populations.

Step 3: Determine potential for the identified health hazards to have a negative impact on B.C.'s Mountain Caribou

a. Low genetic variability

Genetic variability influences disease transmission, susceptibility and the ability of an infection to establish itself in a population. We are unaware of studies that demonstrate the link between diminished genetic variability and caribou health. More information is needed before the health impact of low genetic variability can be assessed.

b. Limited winter food availability

Poor nutrition can lead to increased disease susceptibility, increased potential for predation, reduced reproductive fitness, and reduced thriftiness in calves. Both the level of malnutrition in Mountain Caribou and its relationship to the adverse outcomes listed above are unknown.

c. Susceptibility to infectious agents

Spalding (2000) reported on evidence that several caribou populations in B.C. had experienced disease outbreaks in the early 1900s. These reports have not been validated nor were the nature or extent of diseases known or described. However, this suggests that the potential exists for infectious disease to negatively impact B.C. caribou populations. In most situations, further information is needed to determine if an infectious disease agent is causing adverse health outcomes in Mountain Caribou. As an example, consider the potential impact of besnoitiosis.

Besnoitiosis, caused by the protozoan parasite *Besnoitia tarandi*, is a disease of cervids and bovids, primarily caribou and reindeer. It is often unapparent but can manifest as skin lesions and blood vessel occlusion. Its life cycle is still unknown. One survey found overall parasite prevalence of 23% in woodland caribou throughout B.C., the highest levels were found in the far north and northwestern areas of the province. There have been no reports of disease caused by *B. tarandi* in wild cervids in B.C. despite some

limited surveillance. However, severe besnoitiosis has been reported in caribou, mule deer and reindeer at two zoos in western Canada. The Animal Health Branch of the B.C. Ministry of Agriculture and Food carried out a transmission trial and found no evidence of transmission from infected caribou (20 animals) to mule deer (20-25 animals) after one year of living in adjacent pens. The probability of disease in caribou and transmission to other species is difficult to estimate because the lifecycle of *B. tarandi* and risk factors for disease are unknown. Unfortunately, due to our lack of information on the nature of disease caused by this parasite, it is difficult to estimate the associated risk. More research is needed before we will be able to fully evaluate the impact of this hazard to B.C. Woodland Caribou populations.

d. Potential for translocation events

Translocation of animals is usually viewed as a last attempt to recover a species at risk. However, the movement of animals, for either population augmentation or captive breeding purposes, can present a range of health risks including risks from capture methods. One of the most serious potential risks with handling caribou is capture myopathy, a degenerative muscle disease associated with the stress of capture, restraint, and transportation. These hazards present a moderate risk to captured caribou, however mitigation strategies exist to decrease risk to a lower level. At this time, no anesthesia or sedation is used for capture of caribou.

Sifton (2001) outlined health risks associated with captive breeding and head-starting. The most significant risks identified for captive caribou were Johnes's disease, malignant catarrhal fever, besnoitiosis, and capture myopathy, as described above. Besnoitiosis was identified as the most important disease to consider for bovids and cervids held at the breeding facility and fascioloidiasis and besnoitiosis were identified as the most important disease risks for wildlife in the vicinity of the breeding facility. However, good husbandry, management, and quarantine practices, diligent monitoring and ongoing research by all parties involved in the breeding program were believed to be the keys to mitigating these identified risks.

Step 4: Action plans

a. Low genetic variability

Action mode: "gather more data"

As more information is needed before the impact of a low genetic variability on Mountain Caribou health can be assessed, continued research should explore the level of genetic variability and, if possible, the immunological competence of remaining populations (refer to Table 6). The recovery team needs to define a threshold level of genetic variability at which further interventions must be undertaken.

b. Limited winter food availability

Action mode: "gather more data"

The simplest method to determine nutritional status is a gross observation of body condition. There are several body condition scoring systems available for livestock that could easily be adapted for caribou. Biologists should also take advantage of any caribou handling events to do general health assessments (body condition and signs of disease etc) and collect samples for testing and/or archiving (e.g. feces, blood, hair etc). All recently dead caribou carcasses should be submitted for full post-mortem exams and tissues should be archived for future use.

c. Susceptibility to infectious agents

Action mode: “gather more data”

Information is limited about the presence and/or impact of infectious disease in caribou as well as in other wild cervids. In order to collect necessary data to explore this health risk, recovery biologists should take advantage of opportunities for individual animal observations and population studies. All mortality events should be investigated and tissue sampling (see Tables 6 and 7) should be undertaken whenever possible.

Good management, preparation and handling practices will help mitigate undue stress in cases of live animal sampling and thereby reduce disease susceptibility. Reducing contact between caribou and other species (e.g. other wild cervids or domestic livestock) will reduce the potential for disease transfer. Avoidance of non-native species introductions into the province will help prevent introduction of novel diseases .

d. Potential for translocation events

Action mode: “do something”

If it is determined that a caribou translocation is necessary then a plan to mitigate for potential risks associated with the translocation is required. This plan should consider the probability and impact of identified diseases and hazards (this includes transfer of genetic material). An effective translocation plan should include procedures for capture, hygiene, handling, husbandry, quarantine (if needed) and pre-release testing procedures.

6. Who to contact for further assistance or information?

International contacts

World Conservation Union (IUCN-CBG) -- wildlife risk assessment model
United States Geological Survey (USGS) – wildlife biologists, veterinarians etc.

National contacts

Canadian Committee on Animal Care (CCAC) – animal care and handling guidelines
Canadian Cooperative Wildlife Health Centre (CCWHC) -- pathology
Canadian Wildlife Service
Centre for Animal Parasitology, Canadian Food Inspection Agency -- parasitology
Centre for Coastal Health (CCH) –risk assessment, disease outbreak investigations

B.C. laboratories and agencies

B.C. Centre for Disease Control (BCCDC) – zoonotic diseases, public health
B.C. Ministry of Environment, Ecosystem Branch – Dr. Helen Schwantje, wildlife veterinarian
B.C. Ministry of Agriculture and Lands, Animal Health Centre -- pathology, disease testing

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Appendix A: Sample physical examination form.

				What to look for
Date	_____			
Species	_____			
Species ID	_____			
Examiner	_____			
Temperature				Normal temperature range varies among species but generally range from 36°C to 39°C in mammals and 37.7°C to 43.5°C in birds. Increased temperature is indicative of an active infection or stress.
Pulse				Count the number of pulses in 15 seconds and multiply by 4 to get the number of beats per minute. Normal range varies greatly among species (e.g. 30 beats per minute in an elephant and 750 beats per minute in a mouse). Pulse generally increases with stress.
Respiration				Count the number of breaths in 15 seconds and multiply by 4 to get breaths per minute. Normal ranges vary (e.g. 16-40 breaths per minute in cats and 10-14 breaths per minute in horses)
	Normal	Abnormal	Not examined	Details
General appearance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Gross asymmetries, abnormal movement or behaviour, emaciation, excess salivation
Skin/coat/feathers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Evidence of injury (wounds, scars), quality of coat/feathers (discolouration, bald patches), presence of growths or ectoparasites
Musculoskeletal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Skeletal deformity, muscle wasting/emaciation
Circulatory	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Respiratory	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Nasal discharge, breathing pattern (rapid or slow, shallow or deep) and sounds (wheezing). Stethoscope can provide more detail.
Digestive	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Look for signs of emaciation, distended abdomen, diarrhea (feces, staining, redness, swelling or discharge around anus)
Genitourinary	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Eyes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Cloudiness, redness or swelling in or around the eyes, ocular discharge
Ears	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Carriage of ears should be symmetric and should move to respond to stimuli
Mouth	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Colour (should be a rosy pink), lumps, ulcers, dryness and symmetry of gums, condition of teeth
Neural system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Lymph nodes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Samples collected	Yes <input type="checkbox"/>	No <input type="checkbox"/>		
Feces	<input type="checkbox"/>	<input type="checkbox"/>		
Blood	<input type="checkbox"/>	<input type="checkbox"/>		
Hair/feathers	<input type="checkbox"/>	<input type="checkbox"/>		
Other				