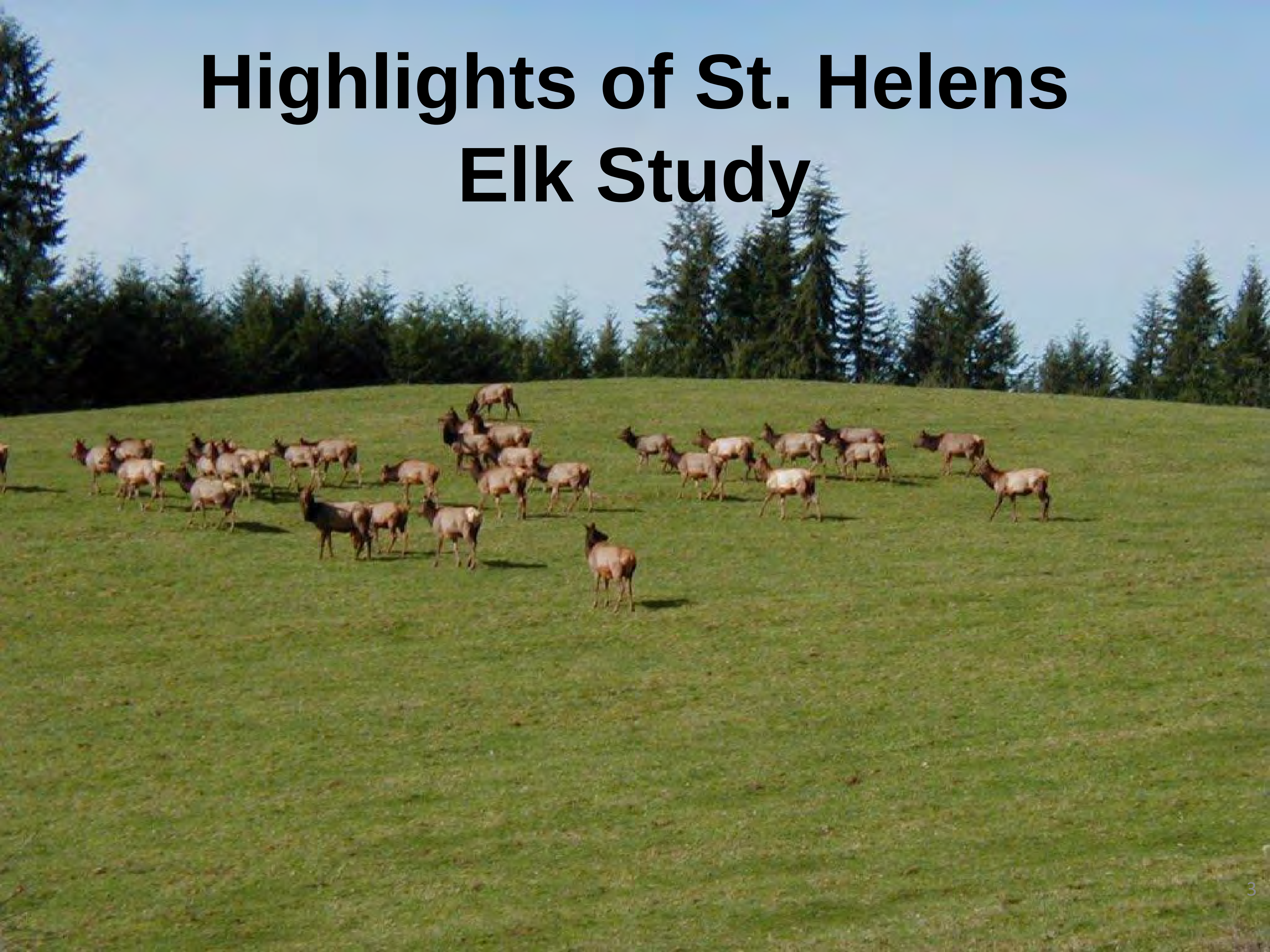
Elk Hoof Disease in Southwest Washington

WDFW Hoof Disease
Public Working Group Meeting
12 February 2014

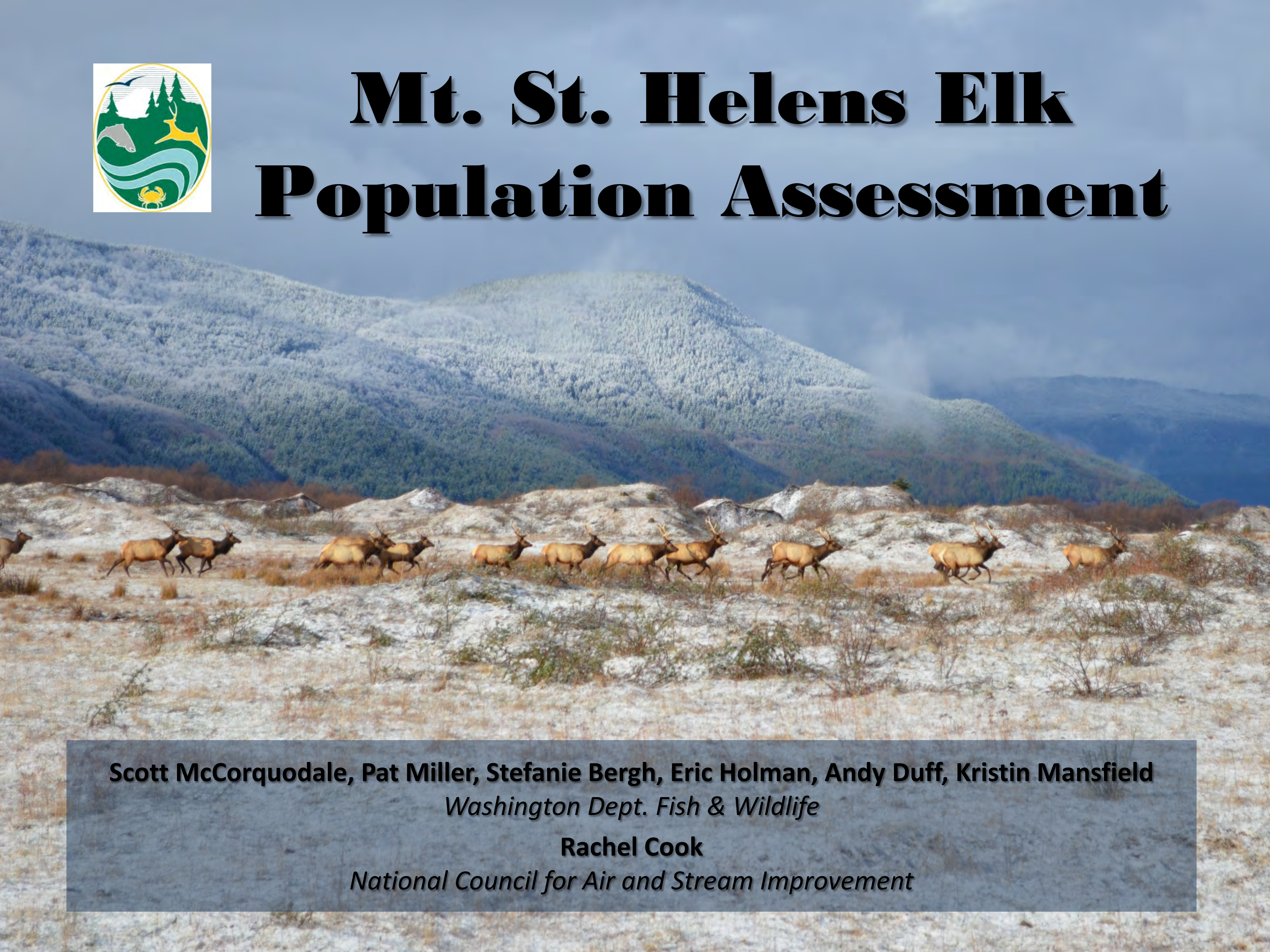
Agenda

- Welcome
- Highlights of St. Helens Elk Study
- WDFW Hoof Disease Investigations Update
- Management Option Matrix
- Draft Next Steps
- Review of Assignments
- Public Testimony

Highlights of St. Helens Elk Study

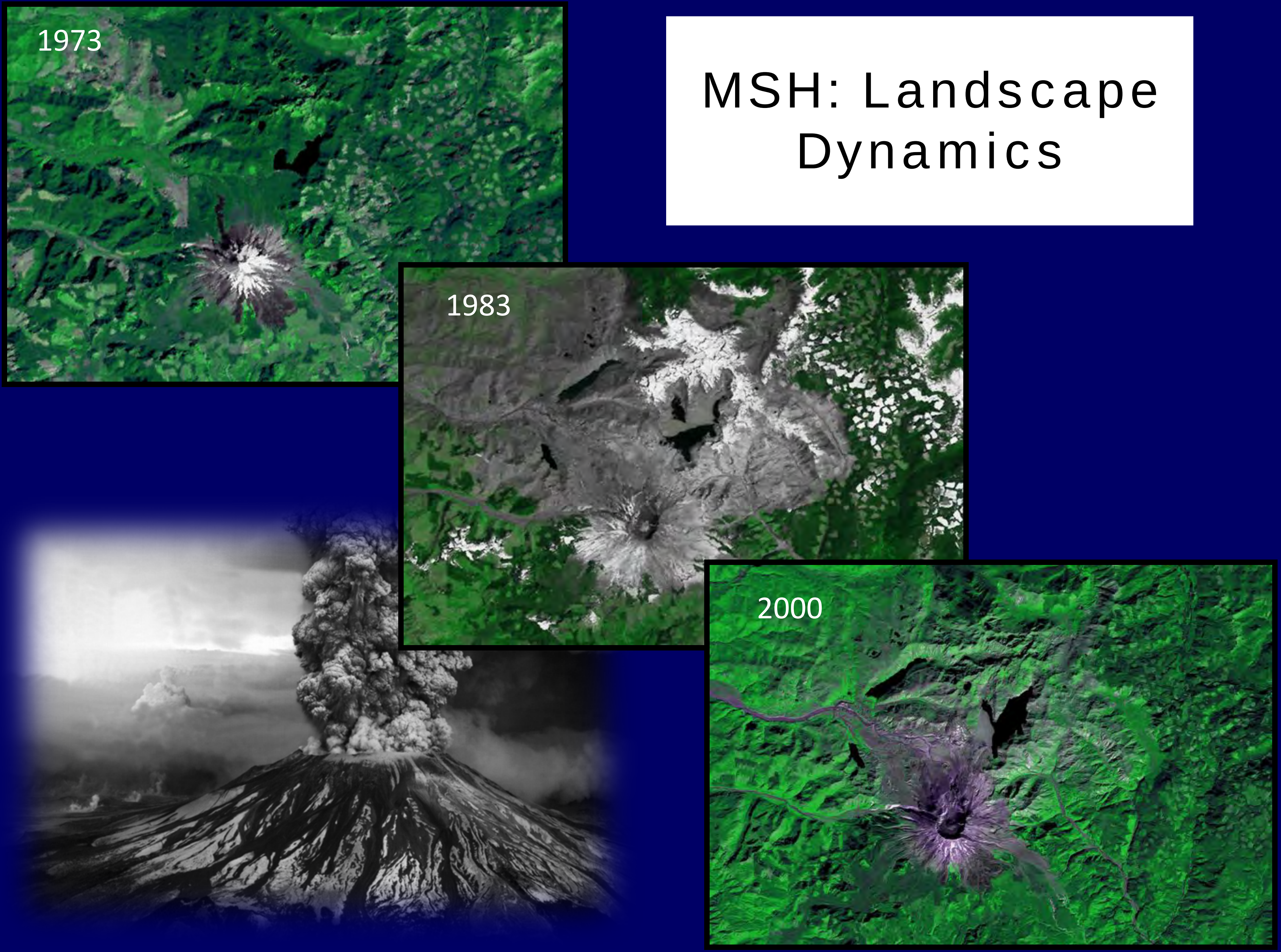


Mt. St. Helens Elk Population Assessment

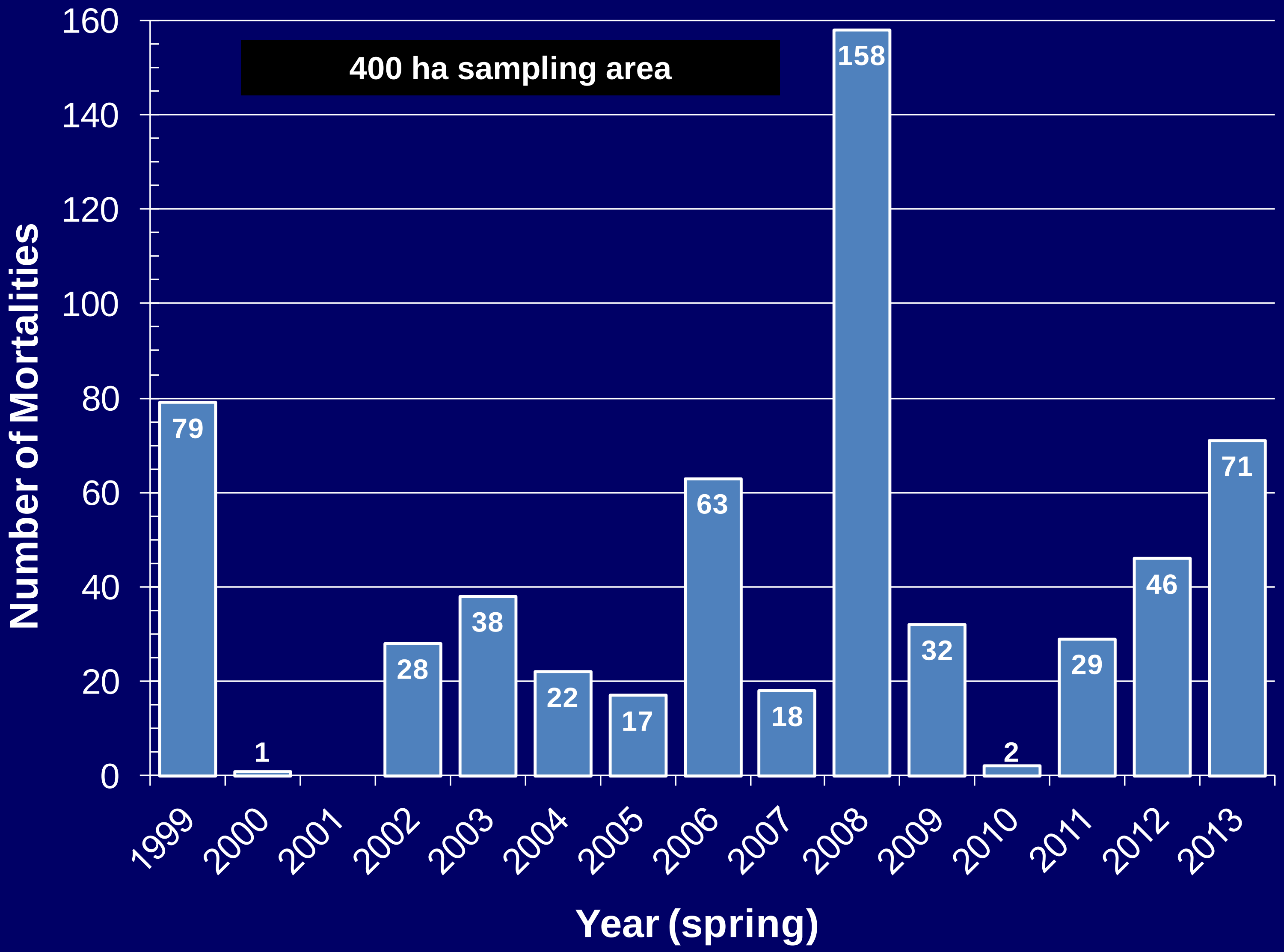


Scott McCorquodale, Pat Miller, Stefanie Bergh, Eric Holman, Andy Duff, Kristin Mansfield
Washington Dept. Fish & Wildlife
Rachel Cook
National Council for Air and Stream Improvement

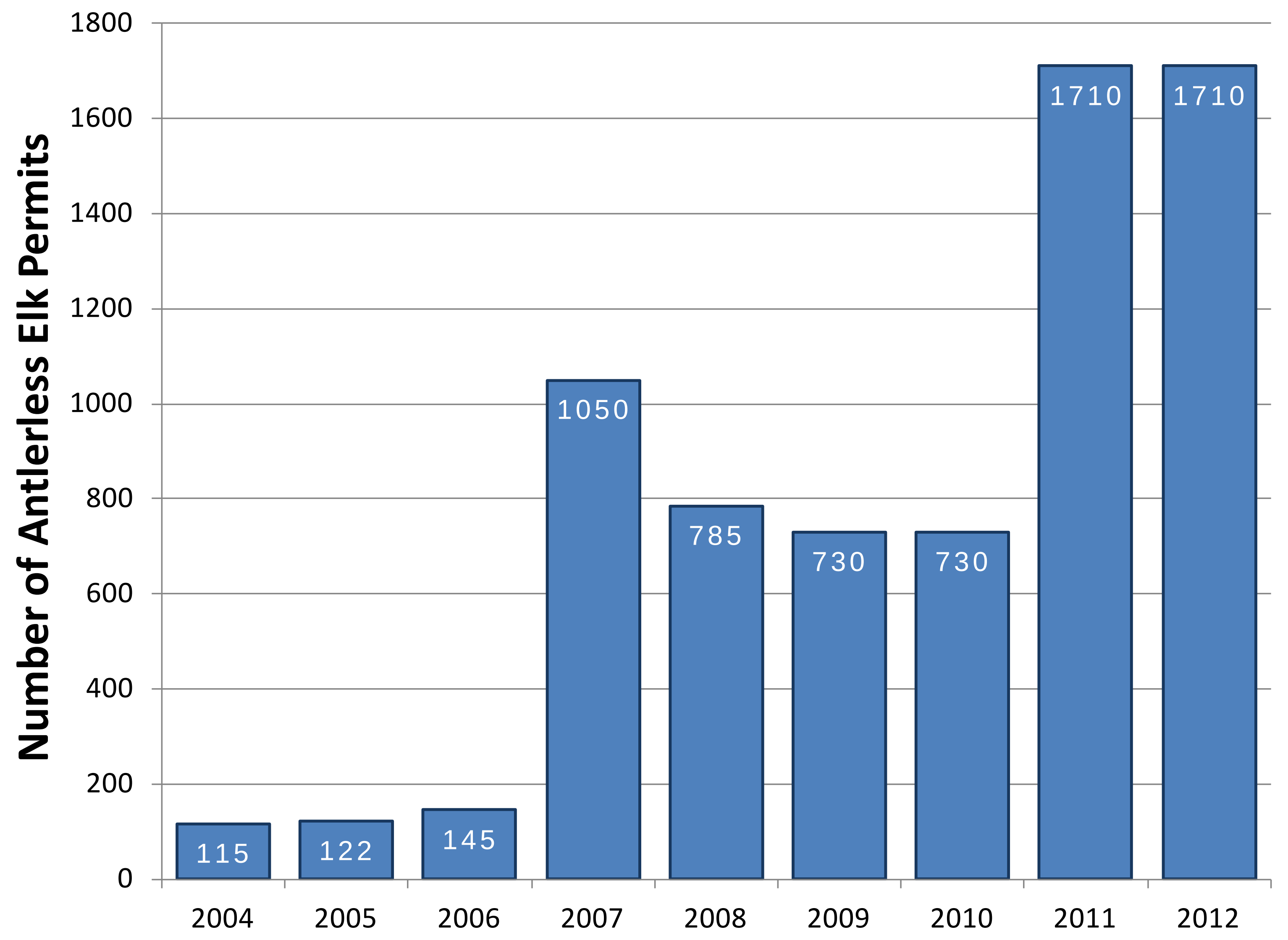
MSH: Landscape Dynamics



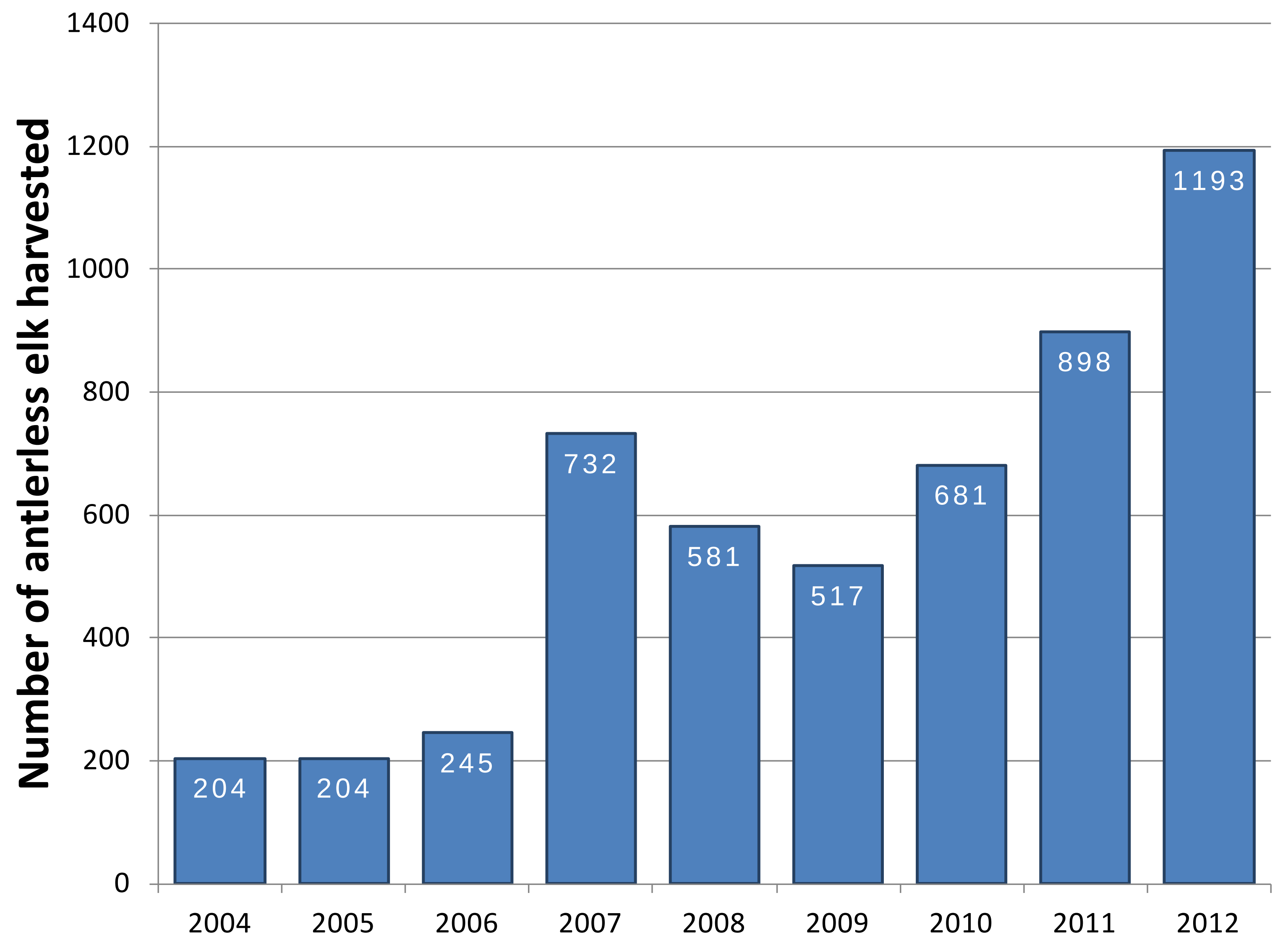
Winter Mortality Index



Recent Antlerless Elk Harvest Strategy



Antlerless Elk Harvest (general and permit)



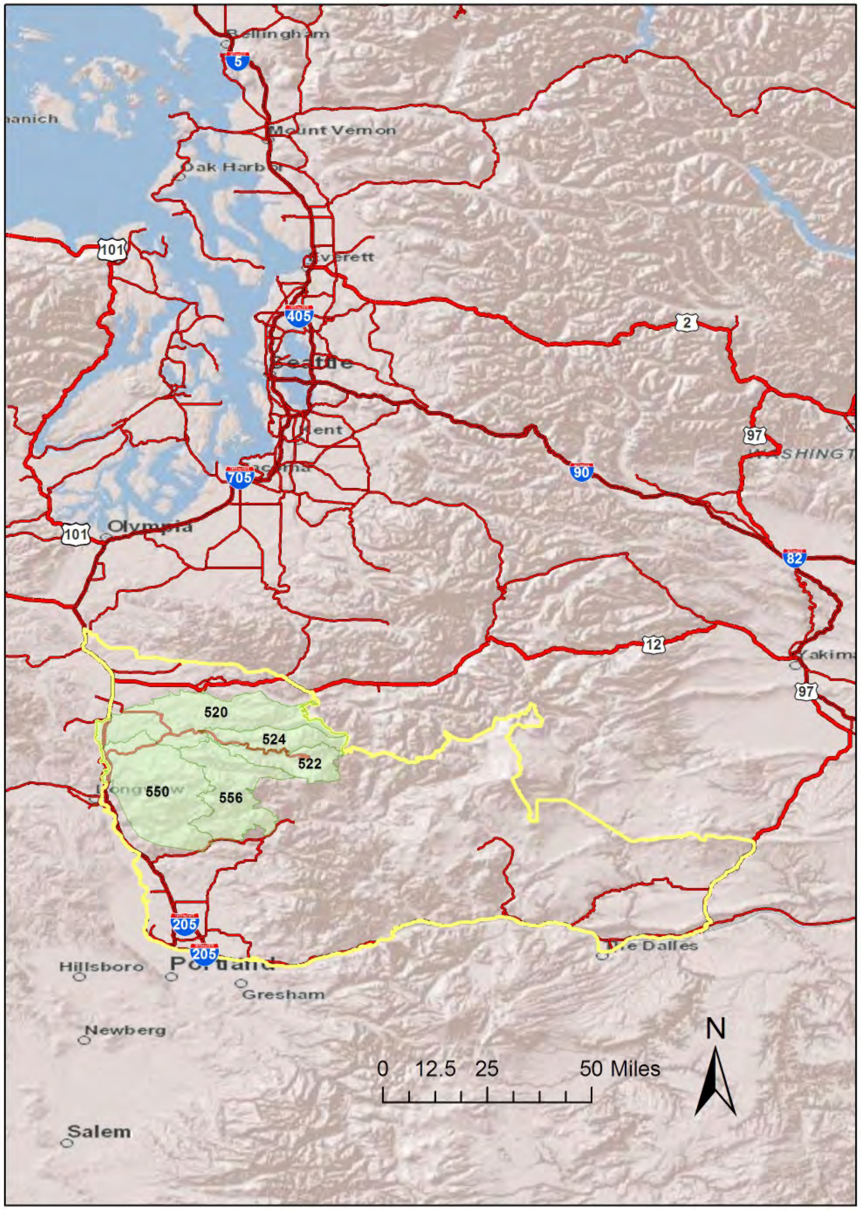
Project Description

- **Develop abundance estimates/indices**
- **Focus on a 5-GMU core study area**
- **Explore aerial survey detection using radiomarked elk**
- **Derive a practical monitoring strategy**
- **Assess elk condition and vital rates**

Study Area

≈ 2,750 km^2

- *5 Core GMUs*



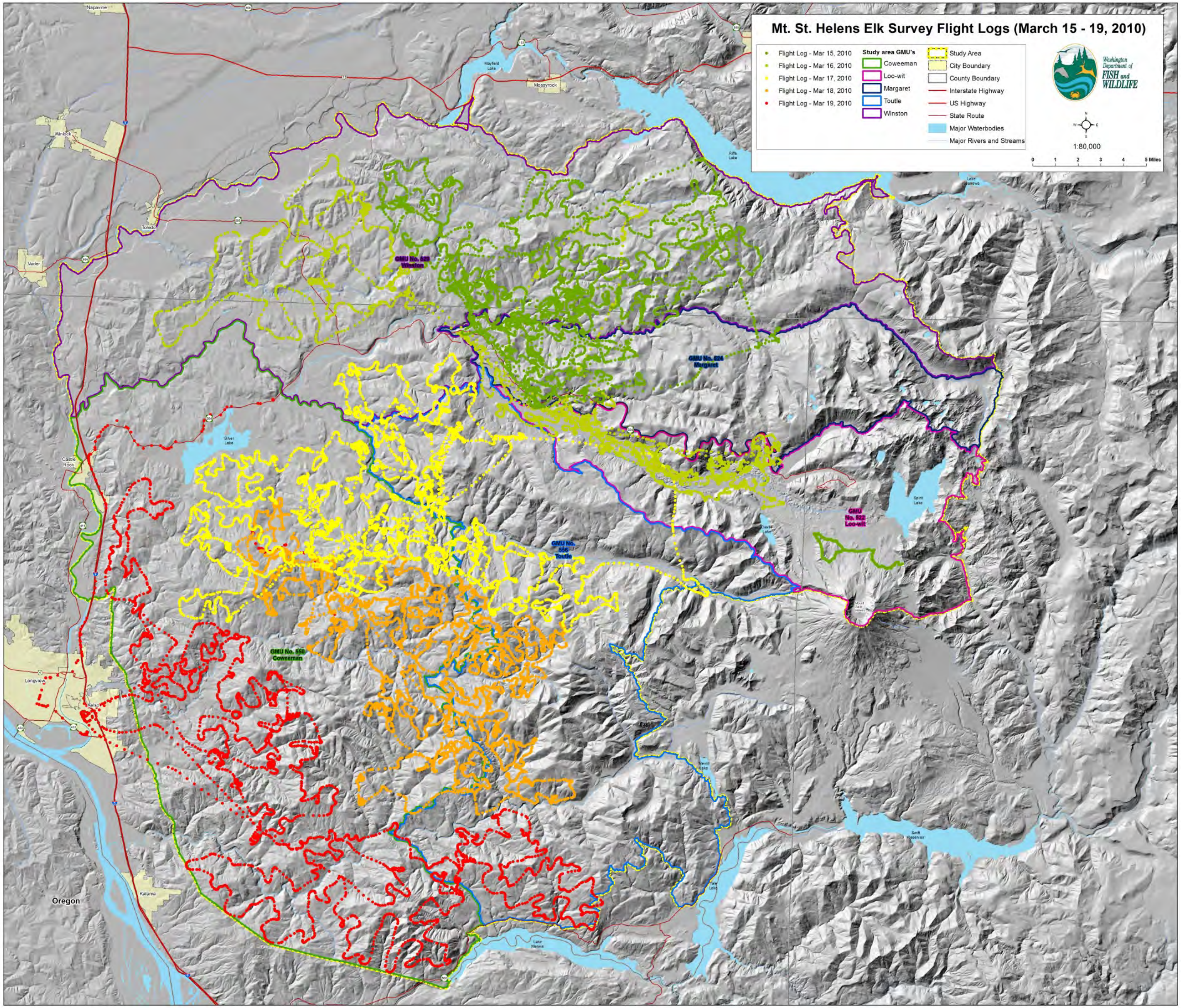
Capture & Marking: 2009-2012

- February helicopter darting
- 151 elk marked: 111 F, 40 M
- Mix of VHF and GPS collars
- Data collected:
  - *Age (tooth for sectioning, sent to lab)*
  - *Girth for mass estimates*
  - *Pregnancy or not for Ad F*
  - *Lactation or not for Ad F*
  - *Body condition for % body fat (Ad F)*
  - *Blood*

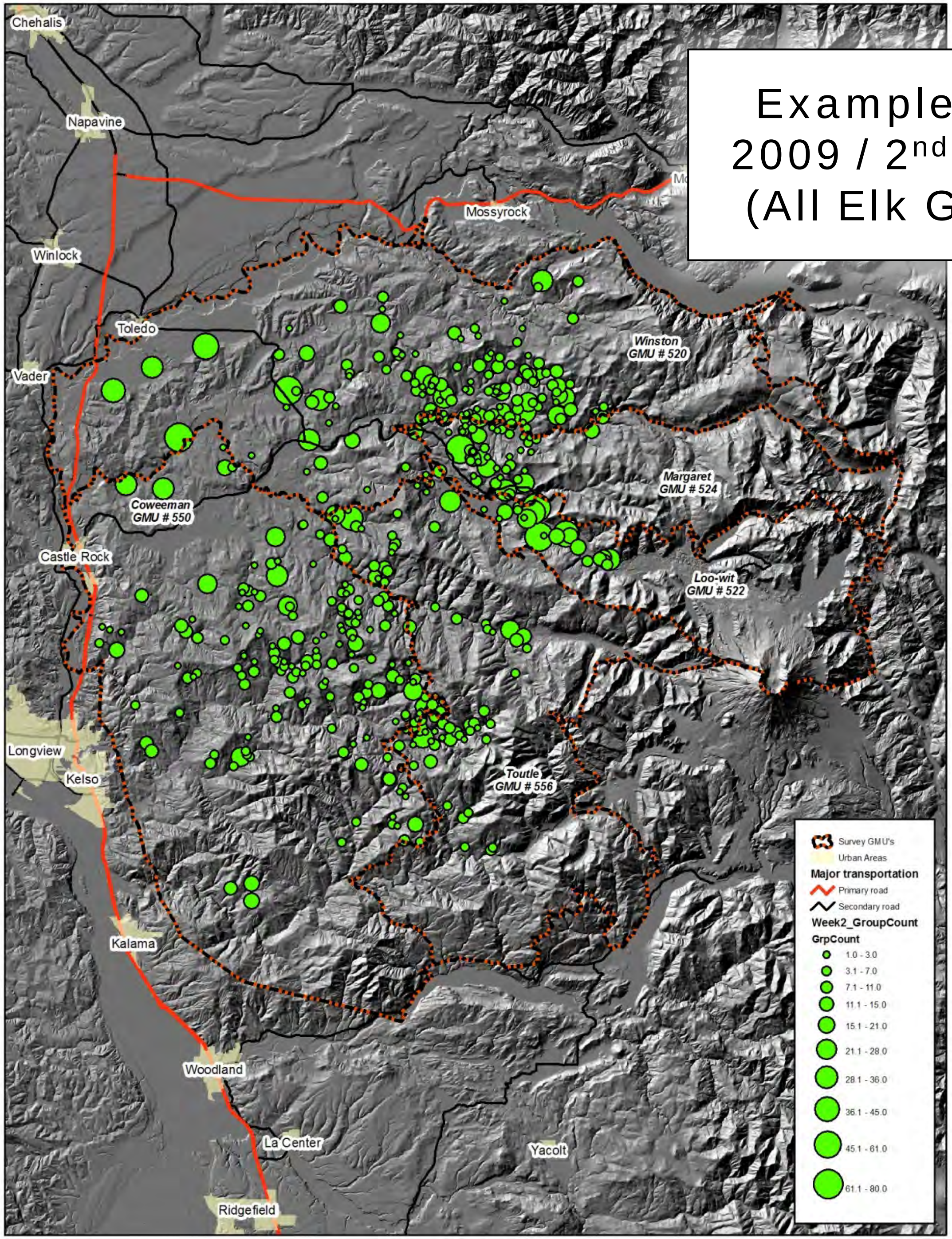
Basic Helicopter Survey Design

- 2 full spatial replicates yearly
- GIS flight logging with orthophoto guide
- Fly all habitats w/ modest-to-good sightability
- March-early April timing
- ≈ 35 flight hrs per replicate
- 3 observers + pilot

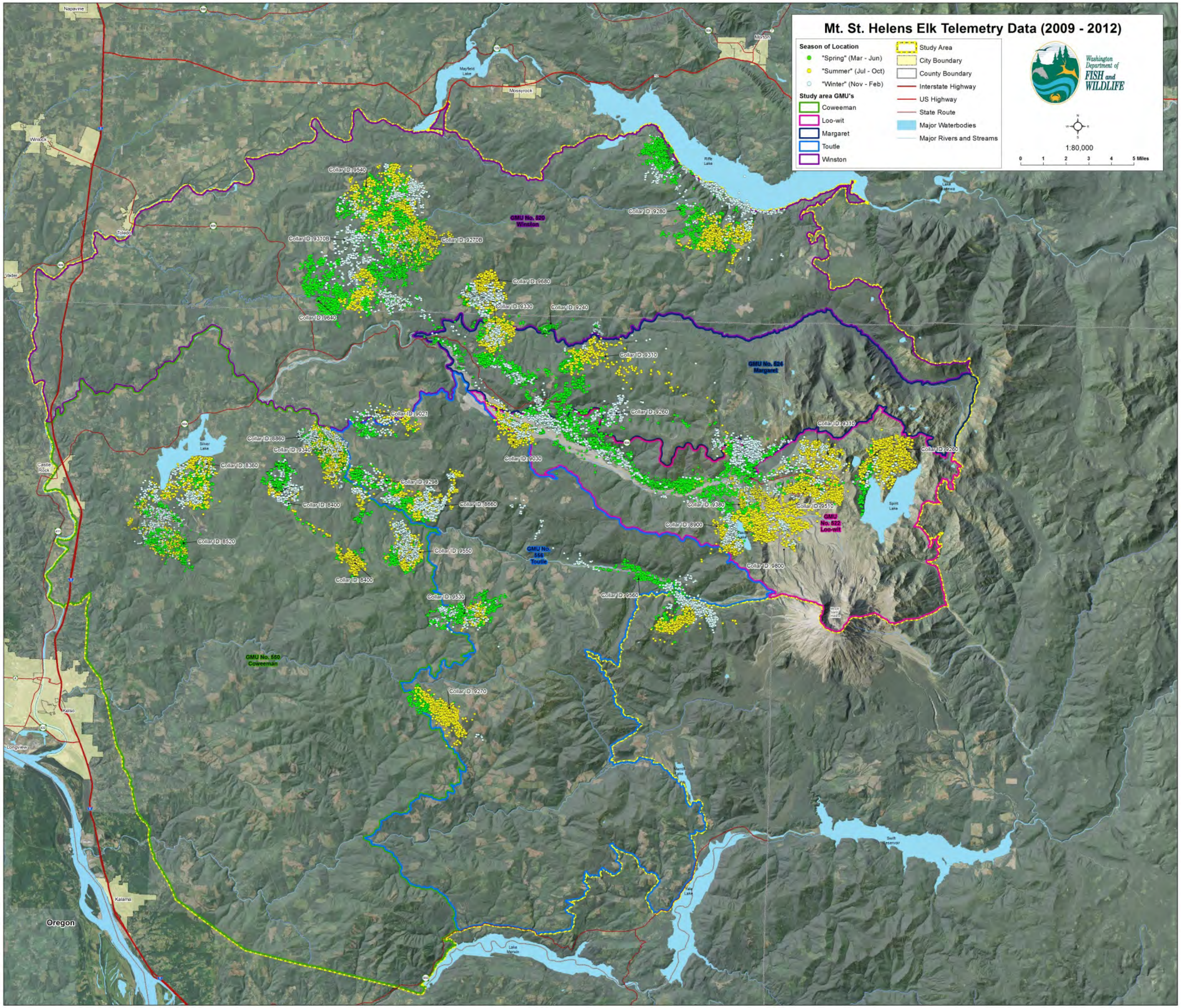
Flight Log Example



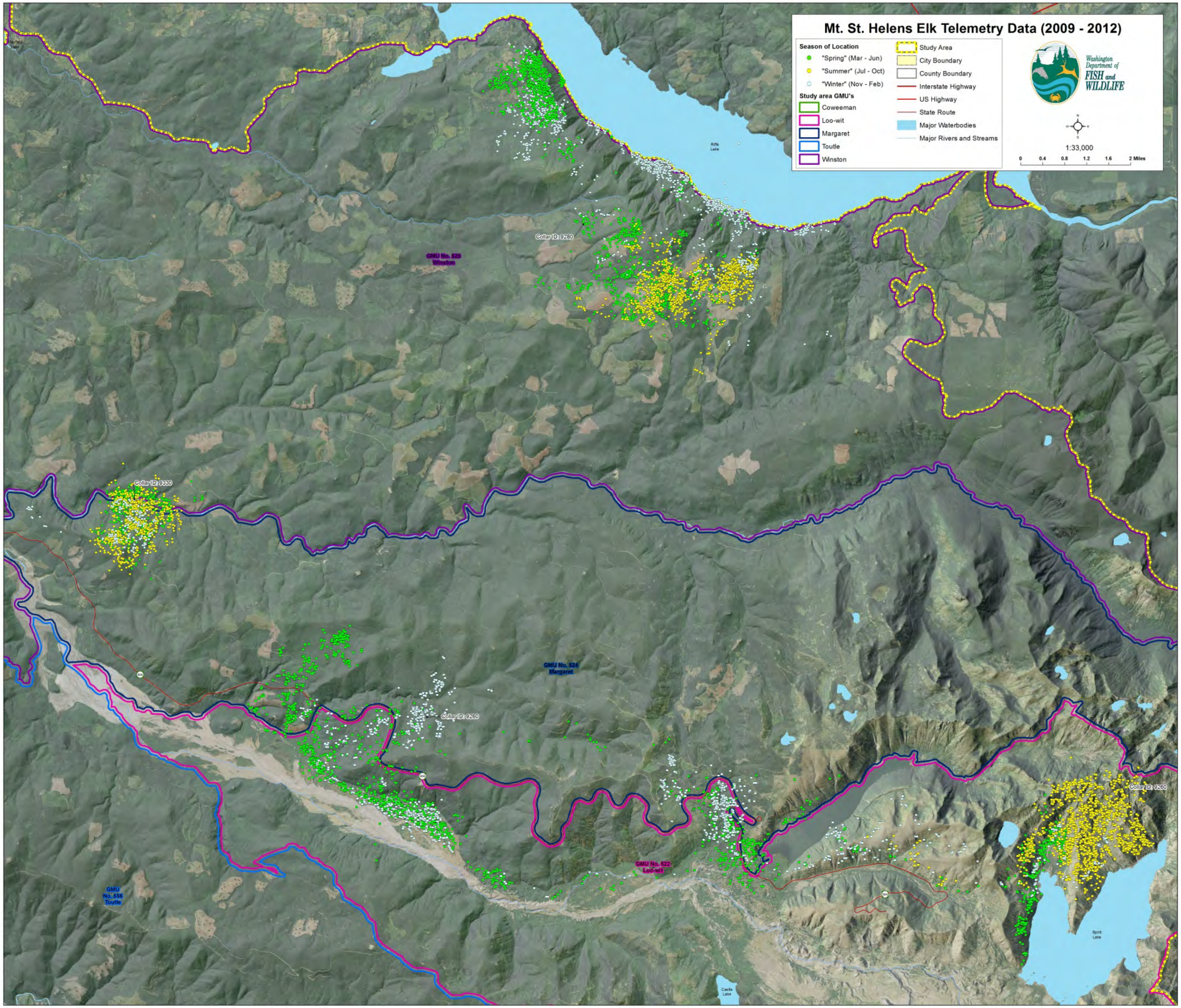
Example Survey Results: 2009 / 2nd Survey Replicate (All Elk Groups Observed)



GPS Collared Elk Location Example



GPS Collared Elk Location Example



Mt. St. Helens Elk Population Assessment

Examples of animation of a radio-collared elk movements

St Helens Elk Collar ID 9260_wImagery_ZoomClose_wPoints.avi

St Helens Elk Collar ID 9280_wImagery_ZoomClose_wPoints.avi

Survival Estimates

- Survival was moderately high throughout the study
- Declined across 5 GMUs over time
- Lower estimates everywhere at end of study
- Coweeman always lower than anywhere else throughout study

Mt. St. Helens Elk Population Assessment

- Overall, the data suggest a decline in total elk and total cow elk abundance on the order of 30% across the 5-GMU landscape, 2009-2013
- But, in GMU 520(Winston), 524(Margaret), and 550(Coweeman) the decline was more substantial
- There was likely a modest decline in GMU 556(Toutle), and did not detect a decline in GMU 522(Loowit)

Mt. St. Helens Elk Population Assessment

- Counts and estimates indicated elk abundance changed most on the western ½ of the study area
  - This may have been partly attributable to the distribution of hunter effort for those possessing antlerless permits
    - The western ½ of the study area is closest to the I-5 corridor and would generally be how most hunters accessed the area (i.e., come in from the west)
- We have no real evidence that hoof disease played a role in the decline in the western part of the landscape, but we also cannot demonstrate that it did not contribute in some way

Mt. St. Helens Elk Population Assessment

- Fall organ collections indicated elk attained a range of condition across the landscape
- Cow elk were generally in a little better shape in the Gorge GMUs(568,572,574,578) and GMU 560(Lewis) relative to the 5-GMU study area
- MSH elk, like most westside elk, do not generally attain the condition typical of Rocky Mountain elk populations in eastern WA and elsewhere

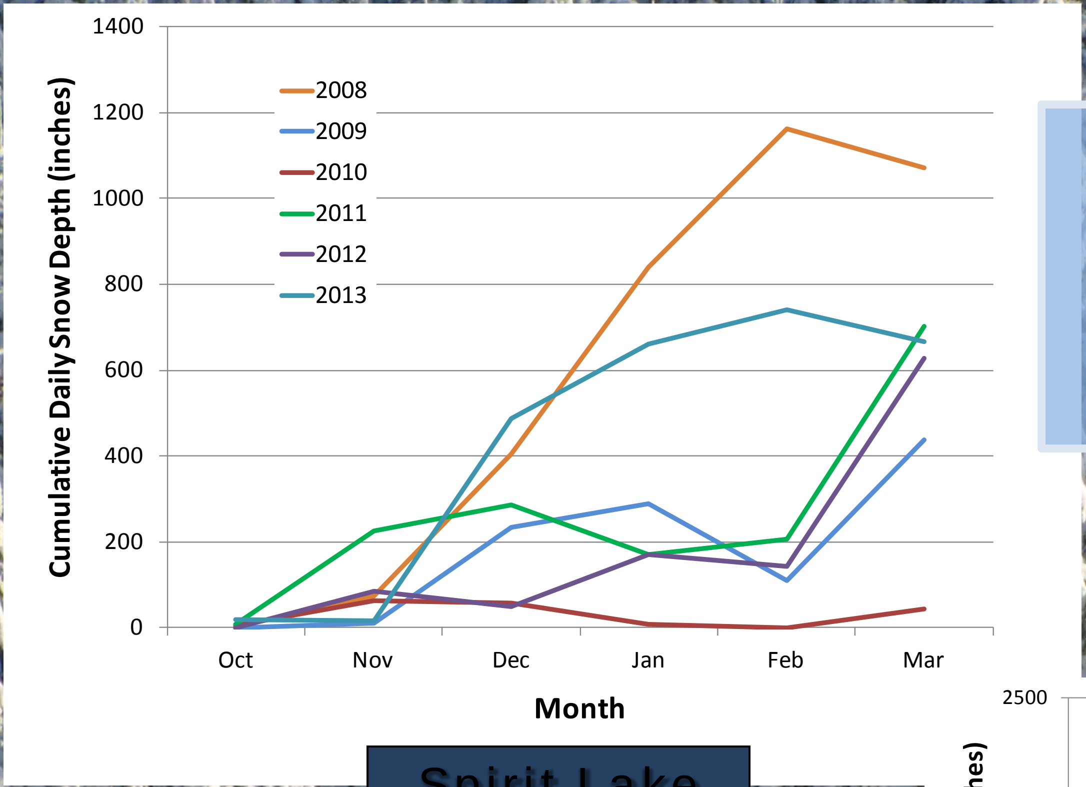
Mt. St. Helens Elk Population Assessment

- We know that when cow elk are at body fat levels from 6-10% in early fall that fertility is impacted to some degree, and successful breeding is unlikely when early fall body fat is 5% or lower
- Mean body fat during November was in the 8-9% range for the study area GMUs and was in the 11-12% range for the other GMUs where hunter-killed elk were sampled from
- Mean body fat for all non-lactating elk was at or above the critical 10% level for all areas in November
    - At the time of breeding, all of these elk would likely have been in a little better shape
- This suggests that most MSH elk are fat enough to have high fertility
    - Lactaters are not likely much above the 10% level

Mt. St. Helens Elk Population Assessment

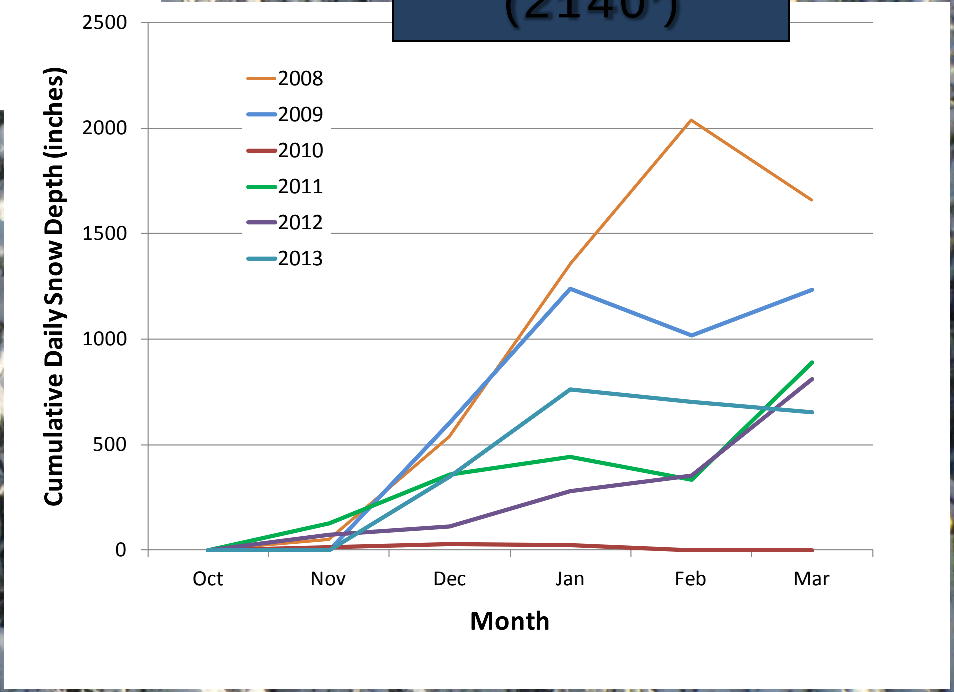
- Among a number of summer and winter weather metrics, overwinter mortality appeared to be most strongly associated with late winter snowfall
  - More elk succumbed to starvation in high snow winters
- The spring calf:cow ratio, adjusted for antlerless elk harvest, was most strongly associated with the previous late summer-early fall rainfall
  - Spring calf recruitment was poorer following a droughty late summer-fall
  - Overall calf recruitment was variable – early increase and then decline near end of study

Winter Severity: SNOTEL data

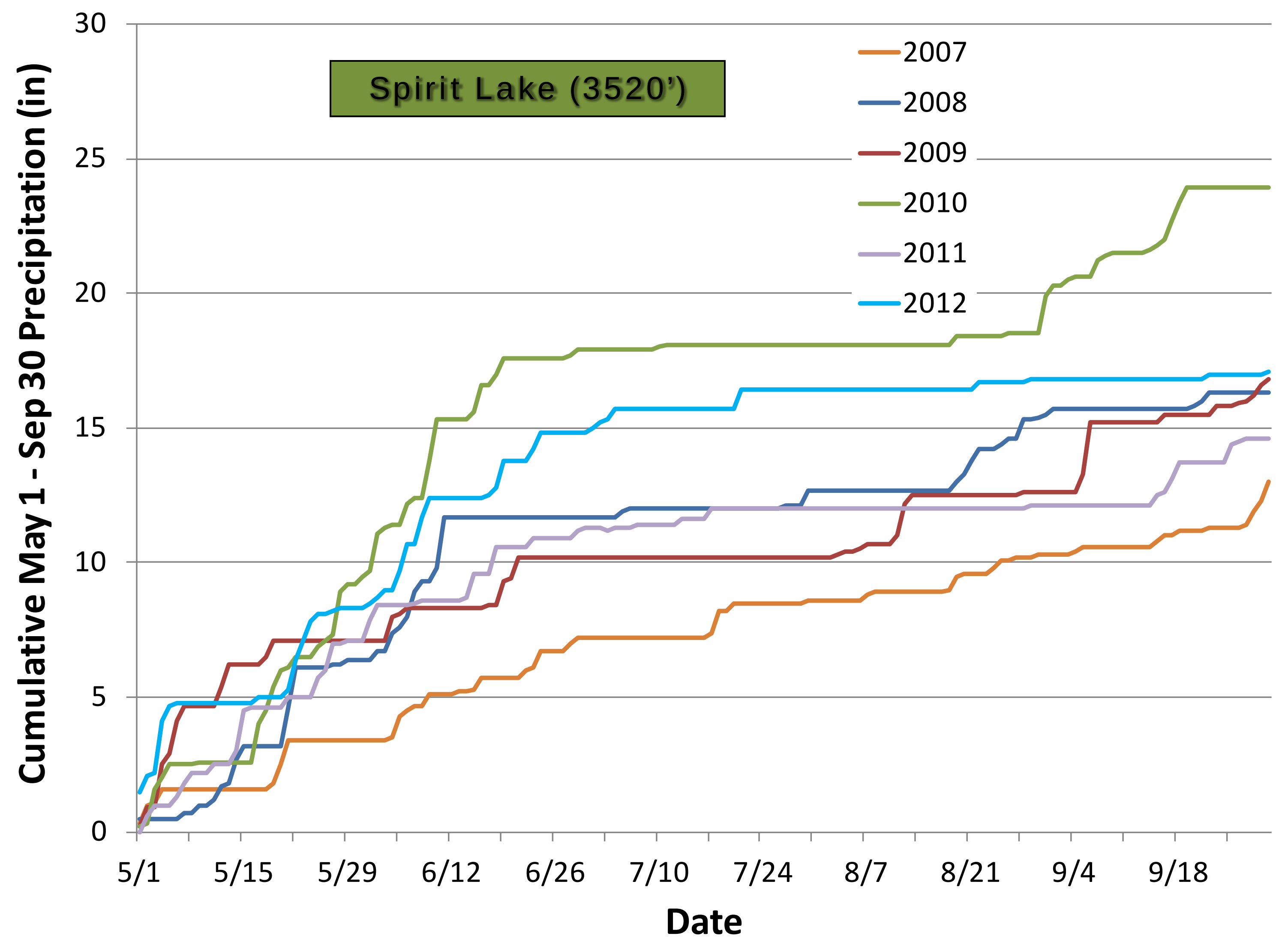


Spirit Lake (3520’)

Pepper Creek (2140’)



Summer Precip: SNOTEL data



Mt. St. Helens Elk Population Assessment

- Although high elk density has likely been a recent-historic contributor to overwinter mortality for both adult and juvenile elk

- There appears to also be weather-mediated effects that operate somewhat independently of elk density

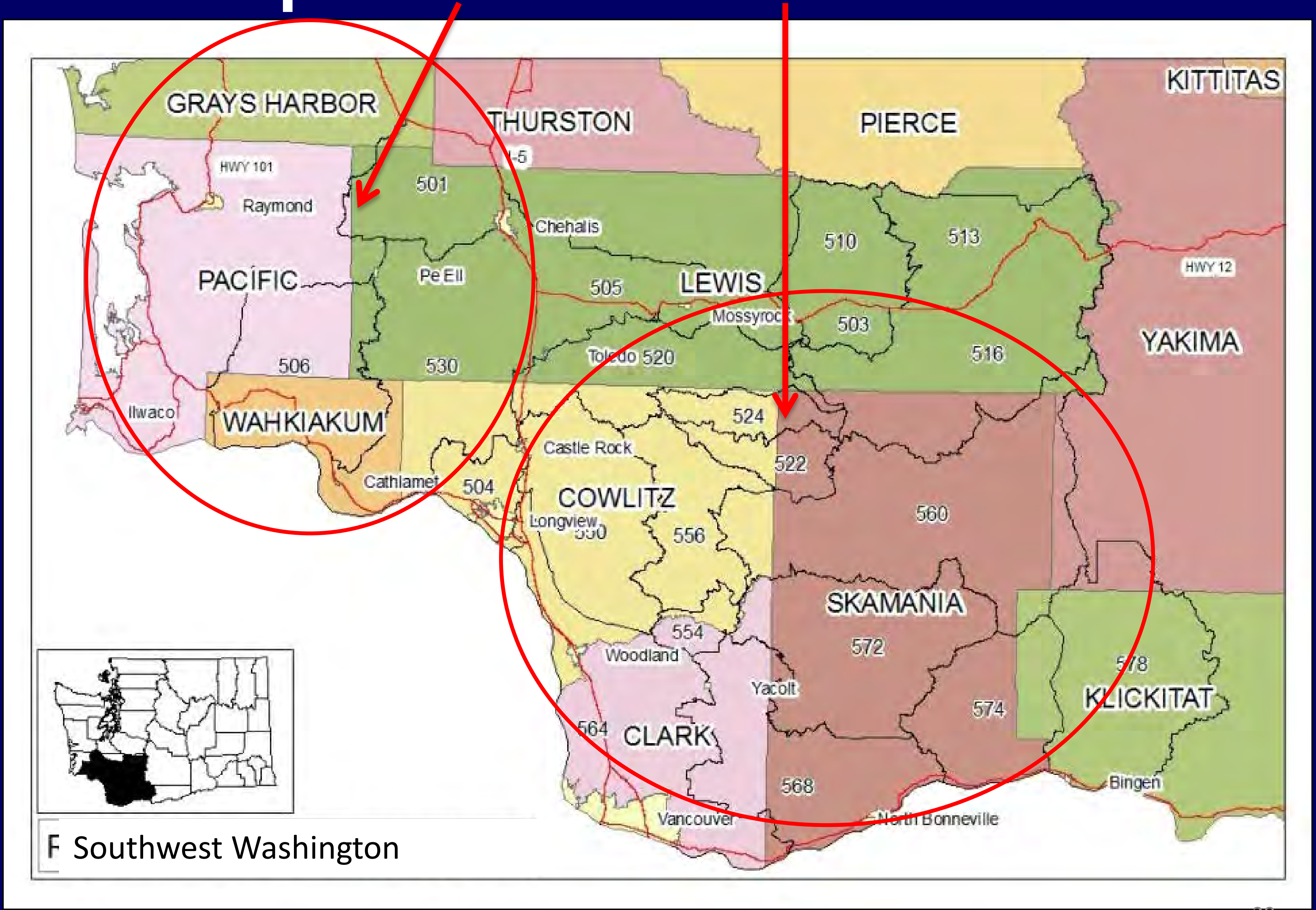
- Under current elk density levels, some episodic overwinter mortality and low recruitment is likely to still occur following snowy winters and/or droughty summer-falls

Mt. St. Helens Elk Population Assessment

- That said, it is likely we have yet to see the long-term effects of a lower elk density
- Vegetative recovery may take some time to occur even with lower elk herbivory; as the plant community is still responding

WDFW Hoof Disease Investigations Update

Willapa Hills and MSH Elk Herds



F Southwest Washington

Sampling and Testing

Histology (microscopic examination) of hooves at CSU

- ✓ Completed
  - Spirochetes are the cause of disease in cattle and CODD in sheep (recent disease in US)
  - Spirochetes found deeply invasive in elk tissue
  - Are they the cause of the disease or secondary invaders to an already diseased hoof?
  - Need further analyses to understand if primary or secondary
  - Most likely playing a role as an infectious agent

Histology of Organs and Tissues, including Muscle, at WSU

- ✓ Completed, no evidence of significant inflammation or infection above hooves, even in severely affected individuals
  - Disease limited to hooves: Other tissues, including meat, are not affected

Trace Minerals at University of Idaho

- ✓ Completed, low selenium and copper, as expected - possible impacts on general health and immunity

Hoof Disease Investigation

- Histology of what were considered possible early lesions on the calves collected last August:
  - When examined microscopically, these keratin and coronary band "defects" were superficial with no associated inflammation or other abnormalities and are likely not significant

Hoof Disease Investigation

- August 2013 calf samples will be “silver-stained” to look for the presence of spirochetes
  - The presence or absence of spirochetes, and their association or lack of association with lesions, will help us evaluate the significance of their detection via histology and/or culture

- Colorado State did not see evidence of spirochetes when re-stained

Collections

- **March 2009** : **Adult elk with chronic lesions**
  3 elk from unaffected area -- East of I-5
  5 elk from affected area -- Cowlitz River Basin

- **March 2013**: **9-10 month elk with acute lesions**
  3 elk from unaffected area -- Pacific County
  4 elk from unaffected area -- Yakima / Kittitas County
  9 elk from affected area -- Lewis / Cowlitz County

- **August 2013: 3-4 month calf elk with acute lesions**
  2 elk from unaffected area -- Grays Harbor County
  5 elk from affected area -- Lewis County

Collections

- **January 2014: 7-8 month calf elk with acute lesions**

  5 elk from unaffected area– Grays Harbor, Kittitas, & Pacific

  7 elk from affected area -- Cowlitz, Wahkiakum, & Pacific

- **Summary: 43 elk examined from March 2009 - Jan 2014**
- 27 from affected area
- 10 from presumed unaffected area (westside controls)
- 6 from unaffected area (east of Cascades)

Specialized Microbiology

Current diagnostic efforts are focused on specialized bacteriology testing to rule out known infectious hoof disease organisms

Including bacterium in**:**

- *Treponema* sp. – to date Spirochete detection associated with this species but not conclusive
- *Dichelobacter nodosus*
- *Fusobacterium necrophorum*
- *Gugenheimia bovis*

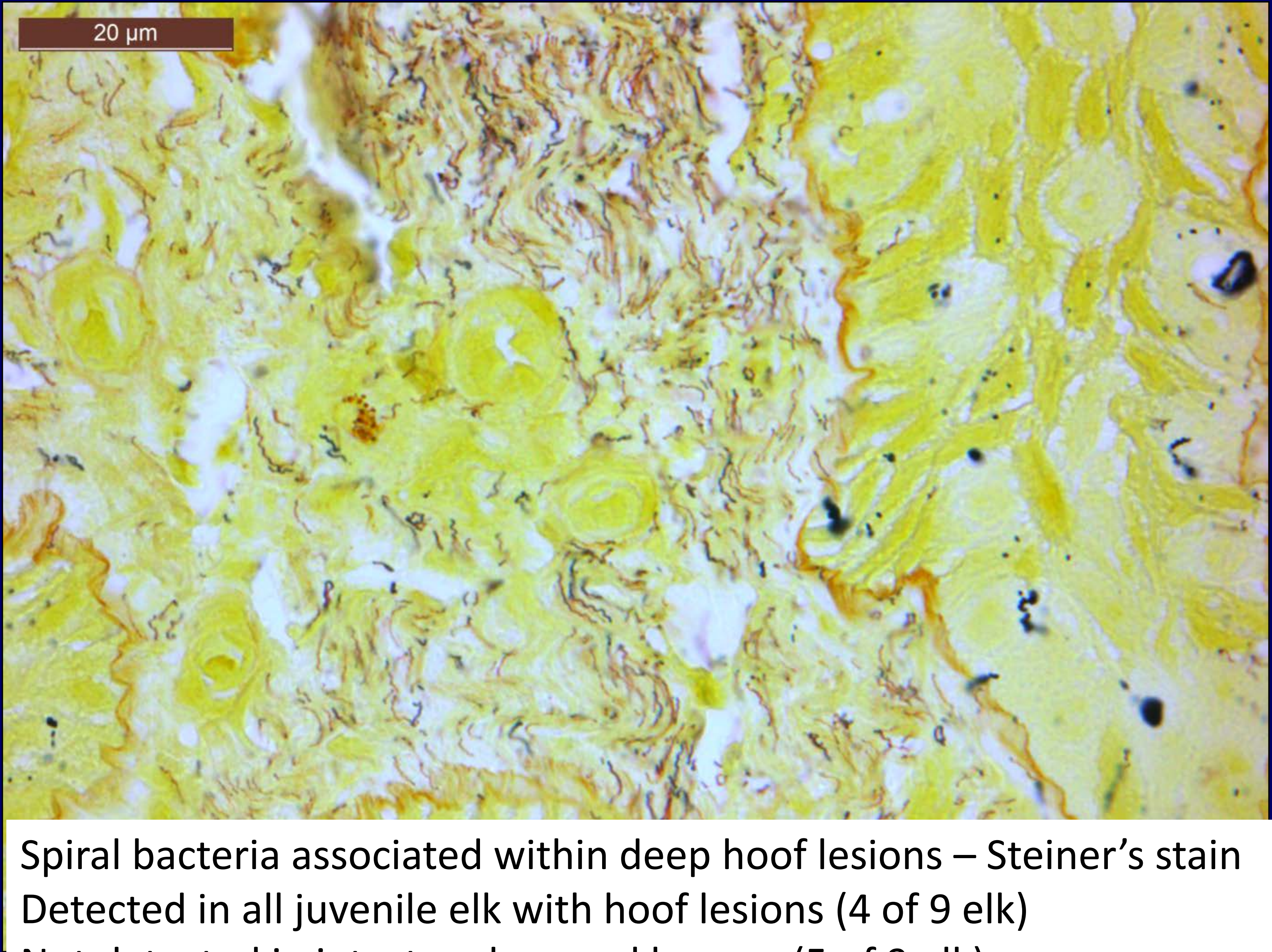
Ongoing Investigations into the Possible Role of *Spirochetes*

- *Spirochete culture and characterization is continuing at the University of Liverpool*

- *Polymerase chain reaction (PCR) tests will be repeated at the WSU veterinary diagnostic lab using samples that have NOT been highly processed (decalcified, dekeratinized, fixed in formalin)*

Ongoing Investigations into the Possible Role of *Spirochetes*

- Treponema *pedis* detected in 2 of 4 samples
  - Using PCR primers that specifically targeted spirochetes/treponemes
- Additional targeted analyses will be conducted to test the remaining samples and tissues from control animals' (unaffected elk) hooves
- These new data support the work in England showing that bacteria in the genus Treponema are present in affected hooves of elk with the disease



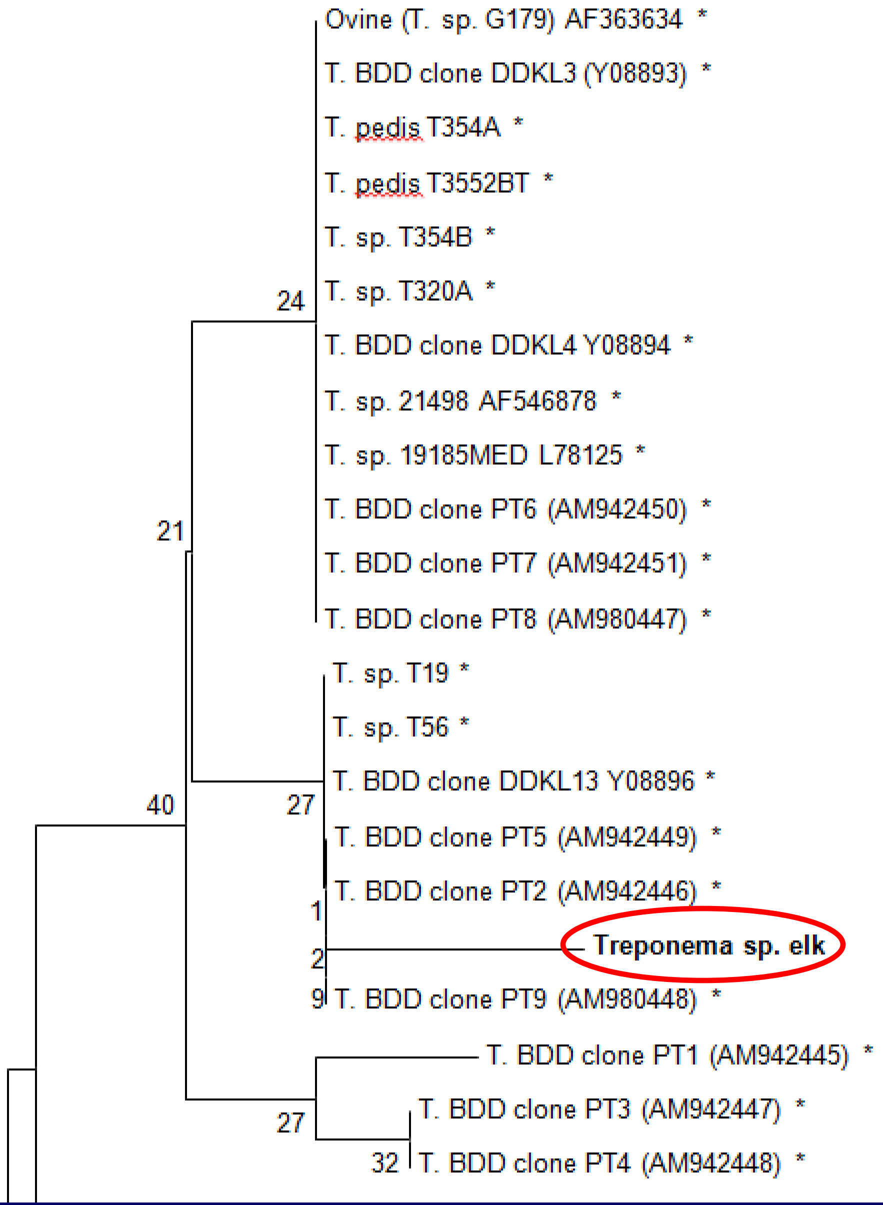
Spiral bacteria associated within deep hoof lesions – Steiner’s stain
Detected in all juvenile elk with hoof lesions (4 of 9 elk)
Not detected in intact and normal hooves (5 of 9 elk)

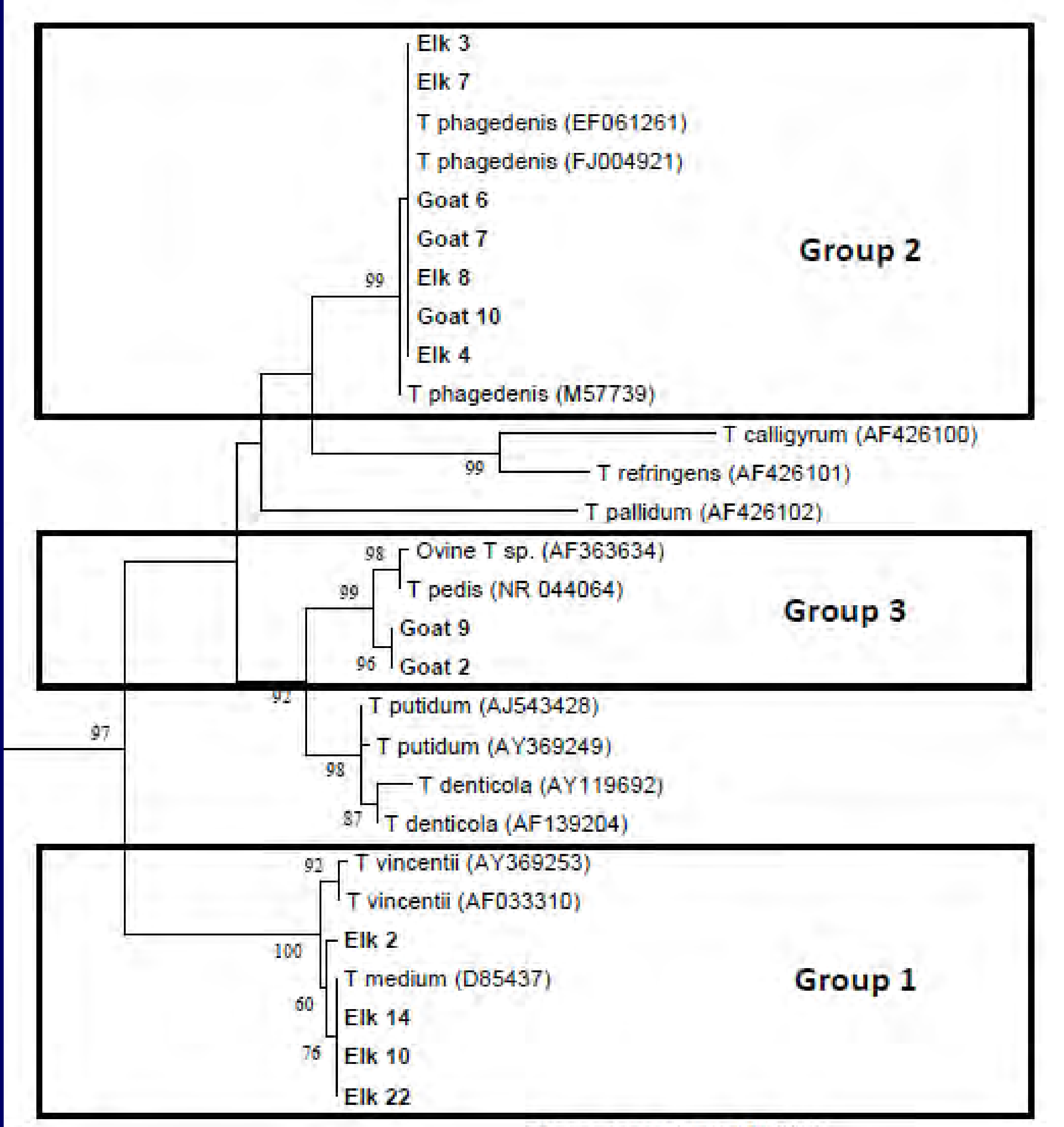
Preliminary

Disease Status and Spirochete Detection

Summer 2013

ELK ID	County	Population Status	Sample	Spirochetes in Culture	Sequencing Results
017	Grays Harbor	unaffected	CB or IDS	neg	
018	Grays Harbor	unaffected	CB or IDS	neg	
021	Lewis	affected	IDS	neg	
022	Lewis	affected	lesion	pos	T. medium (2 isolates)
022	Lewis	affected	IDS	neg	
022	Lewis	affected	contra	neg	
023	Lewis	affected	lesion	pos	T. phagedenis subsp. Vaccae (2 isolates)
023	Lewis	affected	CB	neg	
023	Lewis	affected	contra	neg	
024	Lewis	affected	lesion	pos	T. medium T. phagedenis subsp. Vaccae
024	Lewis	affected	CB	neg	
024	Lewis	affected	contra	neg	
025	Lewis	affected	CB	neg	T. medium
025	Lewis	affected	IDS	neg	


Ovine (T. sp. G179) AF363634 *
T. BDD clone DDKL3 (Y08893) *
T. pedis T354A *
T. pedis T3552BT *
T. sp. T354B *
T. sp. T320A *
T. BDD clone DDKL4 Y08894 *
T. sp. 21498 AF546878 *
T. sp. 19185MED L78125 *
T. BDD clone PT6 (AM942450) *
T. BDD clone PT7 (AM942451) *
T. BDD clone PT8 (AM980447) *
T. sp. T19 *
T. sp. T56 *
T. BDD clone DDKL13 Y08896 *
T. BDD clone PT5 (AM942449) *
T. BDD clone PT2 (AM942446) *
Treponema sp. elk
T. BDD clone PT9 (AM980448) *
T. BDD clone PT1 (AM942445) *
T. BDD clone PT3 (AM942447) *
T. BDD clone PT4 (AM942448) *
24
21
40
27
1
2
9
27
32


Elk 3
Elk 7
T phagedenis (EF061261)
T phagedenis (FJ004921)
Goat 6
Goat 7
Group 2
99
Elk 8
Goat 10
Elk 4
T phagedenis (M57739)
T calligyrum (AF426100)
99
T refringens (AF426101)
T pallidum (AF426102)
98
Ovine T sp. (AF363634)
99
T pedis (NR 044064)
Group 3
Goat 9
96
Goat 2
92
T putidum (AJ543428)
97
T putidum (AY369249)
98
T denticola (AY119692)
87
T denticola (AF139204)
93
T vincentii (AY369253)
T vincentii (AF033310)
Elk 2
100
T medium (D85437)
Group 1
60
Elk 14
76
Elk 10
Elk 22
T saccharophilum (M71238)

Additional Ongoing Diagnostic Efforts

- *PCR tests for certain* ***viruses*** *will be repeated at the WSU veterinary diagnostic lab, using samples that have NOT been highly processed (decalcified, dekeratinized, fixed in formalin)*

- PCR results for viruses that sometimes produce lesions similar to what CSU saw microscopically

- The virus PCRs were all negative

Pending Analyses

- *Samples will be submitted to the UC Davis veterinary diagnostic lab for immuno-histochemistry tests for spirochetes known to cause hoof disease in cattle*
  - Results pending

- *Slides will be sent to one of the world’s top bovine hoof disease experts in New Zealand for his opinion(s)*
  - Results pending

Pending Analyses

- Diagnostics are still ongoing
  - i.e., Determining primary or secondary causes

- Specialized microbiology ongoing (**University of Liverpool, Washington State University, and USDA)**
  - Isolation attempts from August 2013 and January 2014 collections
  - Sequencing of any isolates for known hoof disease pathogens

Management Options

Next Steps

- Handouts
  - Management Options and HDPWG Input
  - Matrix with Management Options and Research Questions
    - Started process of taking all HDPWG, HDTAG, and WDFW staff input into consideration to develop management approach
  - Draft Next Steps

Next Steps

- Notes:

Thank you

….any questions….

Hoof Disease Public Working Group
12 February 2014

Discussion: Examples of Management Options

During discussion, evaluate if any of these examples of management options are likely to be effective and consider:

- Effect on population
- Cost
- Feasibility
- Sustainability
- Resources
- Priority

A. MANAGEMENT OPTIONS

1) REDUCE ELK DENSITY

- Reduce transmission and advancement
- Increase nutrient level of remaining animals
- Removal of elk:
  - Targeted removal and/or increase recreational permits
  - Remove animals in “newer areas”
  - Local/small areas; not landscape level

Questions/Concerns:

- How effective if pathogen (bacteria) is in soil
- Immunity in some animals/areas
- Access, public willingness

HD Public Working Group Input

a) Concern about shooting healthy elk (left with diseased animals e.g., Wahkiakum Co)
b) Alter hunting season structure – to allow for resting period
c) Cull diseased animals – as soon as reported, destroy
   i. Work with landowners
   ii. Can do this despite if know the cause of HD
   iii. May help with understanding genetics?
   iv. Premature to cull until know cause
   v. Consider alternatives such as treatment on “terminally ill” elk
d) Balance of letting survive or culling

e) Reality – Hoof Disease is in SW WA and will likely stay in herds – can't eliminate – but can control
f) Response needs to be a prolonged sustained effort that needs to be feasible
g) Find cause and effect; then manage
    i. Long term goal: Hoof Disease needs to be limited in the herd
h) Containing the disease should be first priority if we can before it spreads more to other areas of NW
    i. Implement while still figuring out the cause – not wait to know the cause
i) Define perimeter to contain HD
j) Develop criteria and policy to implement
k) Can this be established
l) Sustain hunting removal
m) What about elk that slip by?
n) How to achieve this goal?
o) Need public acceptance of a "no elk zone"

2) TREATMENT

- Treat elk - increase elk immunity and nutritious status
    - Test on captive elk
- Treat soil

Questions/Concerns:

- Challenge of achieving treatment on a landscape level
    - Difficult to treat animals
    - Difficult to treat soil on landscape level
    - Bacteria can develop resistance
- Life cycle of bacteria
    - In different conditions (dry/wet, elevation, etc.)
    - Difference of hoof disease between wet and dry land
- Permanence/prevalence of bacteria in environment & elk
    - Different elevations have different prevalence rate
    - Soil composition/Density in soil

HD Public Working Group Input

a. Captive elk – treat and monitor (small study sample to see effectiveness)
b. Before culling: how long do animals live with it?
    i. Understand which treatment works, to help understand the cause

    ii. Selecting animals for treatment might be difficult
        1. Advanced cases cannot be treated successfully
c. Food supplements as treatment?
    i. Change in diet?
    ii. Feeding stations?
        1. Concerns about habituation, concentration of disease, etc.
        2. Difficult to isolate variable that makes the difference (so many variables at play)
        3. Challenge at population level
        4. Find animal btw 3-9 months old and treat to see if treatment is effective
        5. Looking to find cause – not a solution to population scale HD
            a. Would answer Q, might not be feasible to move out to larger scale
            b. Need to develop Qs before figuring out process to get to "answer"
            c. Question about habitat
d. Is effect of chemicals on hooves being looked at?
    i. To date no evidence of toxins in hoof samples
e. Non-infectious options that lead to inflammations, etc. – careful systematic approach essential to determine what is actually going on
f. Need results from early cases before moving forward
g. What else can we do while waiting for diagnosis?

3) LET DISEASE RUN ITS COURSE

Questions/Concerns:

- How to determine if effective
- Public concern
- Sustainable overall population health

HD Public Working Group Input

a. Did that for hairloss syndrome – don't believe deer have recovered, don't do again
b. Premature decision – don't know effect on herd yet
    i. Decisions about continuing hunting, etc. need to be made while "running its course"
c. Set a timeline for analyses and if don't receive results, move forward with management options
d. Narrowed window down to winter of first year for testing
e. Ask hunters to bring hooves in from hunter killed animals

f. Cull elk at epicenter and get samples from there
g. No, at this time – keep looking into disease, etc., and monitor results.
h. Culling has failed at reducing transmission of CWD

4) CONTAINMENT AREAS

- Keep elk off/out of core area
- Fencing of affected areas
- Removal of animals

Questions/Concerns:

- Feasibility
- Private property
- Maintenance
- Wildlife corridors

HD Public Working Group Input

a) Define perimeter to contain hoof disease
    i. Develop criteria and policy to implement
    ii. Can this be established?
    iii. Sustain hunting removal
    iv. What about elk that slip by?
    v. How to achieve this goal?
    vi. Need public acceptance of a "no elk zone"
b) Economically difficult to do
c) Could work in certain situations
d) Do not have enough information to know if containment is appropriate
e) Can't isolate areas
f) At this time given we don't know cause, if can recover – maybe contain in areas where has not occurred before "newer areas"
g) Barriers to prevent movement between areas?
h) Look at movement patterns of elk, funnel areas, etc., if containment is to be considered

B. MANAGEMENT/RESEARCH QUESTIONS

1) What is the prevalence of hoof disease in elk?

    a. Observable, subclinical

2) What is the distribution of hoof disease on the landscape?
3) What is the effect of hoof disease on population?
    a. Monitor population growth/decline, survival
4) What is the effect of hoof disease on productivity?
    a. Does hoof disease reduce breeding or likelihood to carry a calf to term?
5) Is there a genetic link:
    a. Propensity?
    b. Resistance?
6) How often do elk die with hoof disease?
7) How will/can diagnosis help to be preventative in the future?
8) Technical Team reviewed results to date: Appears consistent with an infectious pathogen Questions:
    a. Is it environmental, parasitic, etc.?
        i. Oregon has similar habitat and forest practices, but does not appear to be present in elk
    b. Genetic factor?
    c. Once HD in herd – stays – how to respond?
    d. Are the elk & pathogen obligate to each other?
        i. Deer do not seem to exhibit, use same area
        ii. Elk are robust and generalists/long-lived & social
    e. Additional collections to further understand?
9) What are elk migration patterns/corridors to help address hoof disease?
10) Soil composition/Density in soil?
11) Can diseased elk be monitored and treated either in captivity or in wild

****

<u>Meeting Discussion/Comments/Questions from HD Public Working Group Input:</u>

- Urgency depends on the cause
    - Infectious and non-infectious have very different management approaches
    - Need to find early lesions…..finish this investigation to get there
    - Between 3-9 months of age – evaluate
    - Prevalence and range – Question if still expanding? (as we look harder we will find more)
        - If not changing – might not have the urgency
- Management interventions might interfere with understanding prevalence and range
- Difficult to reproduce DD in cattle
- Captive scenario might be difficult to reproduce as well
- Find out the prevalence

- Test on captive elk (e.g., pregnant female and watch)
- Effect of Selenium and Copper on foot/hoof growth/health
    - Immunity and keratin
- Mineral blocks?
    - Let people try and watch
- Elk on Eco Park – study?
- Dual strategy
    - Management and Analyses
- Legislative – funding request
    - Develop as we move forward
- Watch Pacific County – not seeing Hoof Disease right now
- What can be done at the same time while waiting?
    - Other/additional testing?
- Is Hoof Disease natural, normal baseline occurrence?
- Link to something that came into situation/environment that is contagious?
    - E.g., fungal?
- “Disaster Recovery Plan” on how to proceed
- Ask public for cooperation in Counties that don't see HD to report elk with deformities
- Sample 3-9 month old calves

Examples of Hoof Disease Management Options

Management Options	Effect on population	Cost			Sustainability			Feasibility	Public Input/Support	Priority
		1 year	5 year	20 year	1 year	5 year	20 year			
Reduce elk density Cull (targeted removal) Increased recreational permits Remove animals from agricultural areas Remove animals in outlying/newer areas Implement removals by? (e.g., WDFW, hunters, Wildlife Services, etc.)										
Containment Areas Exclude elk Keep elk off/out of core area□ Fencing agricultural areas Removal of animals										
Treatment Treat elk - increase elk immunity and nutritious status Test on captive elk Treat soil (permanence in soil?)										
Let Disease Run its Course										

Examples of Hoof Disease Management Options

Research Questions	Effect on population	Cost			Sustainability			Feasibility	Public Input/Support	Priority
		1 year	5 year	20 year	1 year	5 year	20 year			
Identify and characterize the primary cause of hoof disease *What is the prevalence of hoof disease in elk?* *Observable* *Subclinical (not possible at this time)* *What is the distribution of hoof disease on the landscape?* *What is the affect of hoof disease on population?*□ *Monitor population growth/decline, survival, productivity* *Is there a genetic link?* *Resistance?* *Propensity?* *What are elk migration patterns/corridors to help management?* *Soil composition/Density in soil* *Can diseased elk be monitored and treated either in captivity or in wild?*										

Elk Hoof Disease Public Working Group
Draft Next Steps
12 February 2014

1) Continue Investigations
    a. Identify and characterize cause hoof disease
    b. Results from January 2014 samples
    c. What is the prevalence of hoof disease in elk?
    d. What is the distribution of hoof disease on the landscape?
    e. What is the effect of hoof disease on population (i.e., survival)?

2) Management Actions
    a. Develop WACs/policies:
        i. WDFW will not translocate elk outside of Southwest Washington
        ii. WDFW will propose WAC to require hunters to leave hooves of harvested elk in SW WA at kill site
    b. Develop criteria for euthanasia of affected elk
    c. Continue reduced elk density in core St. Helens GMUs
        i. Precautionary principle – allow for a healthier herd level and reduce possibility of disease transfer
        ii. Continue damage removals along valley floor
    d. Containment
    e. Develop funding proposal for 2015-2017BN budget
        i. Cost-share fencing for landowners
        ii. Population monitoring
        iii. Containment plan implementation

3) Outreach to:
    a. Neighbors: Oregon, Canada
    b. Private Landowners
    c. Public Landowners
    d. Hunters
    e. General Public

Elk Hoof Disease in Southwest Washington

Sporadic reports of lame elk or elk with overgrown or missing hooves have been received in southwest Washington since the mid-1990s. Reports of this "hoof disease" have been increasing, and hunters have regularly seen and sometimes harvested elk with this condition. At times, observers have reported many individuals in a group limping and showing signs of hoof disease, which has been noted in males and females and old and very young animals.

Dozens of hoof diseases occur in domestic livestock. They have many different causes (infectious, metabolic, toxic, nutritional, physical) and varied modes of transmission, prevention and treatment.

The Washington Department of Fish and Wildlife (WDFW) is working with specialists, here and abroad, to better understand what is causing hoof disease in southwest Washington elk. So far, we have ruled out several potential causes and have narrowed the list of possibilities. Preliminary evidence suggests the involvement of an infectious bacterium, although additional results from animals collected in January 2014 will not be available for several months.

Given this complexity, more research is needed to help us better understand and manage this problem. We are coordinating with other agencies and universities to prioritize the work needed. Even if we are able to determine what is causing this hoof disease, it will be very challenging to address it as there are likely very few, if any, treatment options for wild elk. However, understanding the cause of the disease is an important step toward understanding and managing its impacts.

The department has established a technical advisory group composed of veterinarians and researchers to discuss research and management questions and options, and a public working group to share information and communicate with the public.

What is WDFW doing about Elk Hoof Disease?

WDFW veterinary and biological staff, working with national and international experts, have undertaken an exhaustive diagnostic effort to determine the cause of this disease.

For more information:

wdfw.wa.gov/conservations/health/hoof_disease/

Washington Department of Fish and Wildlife

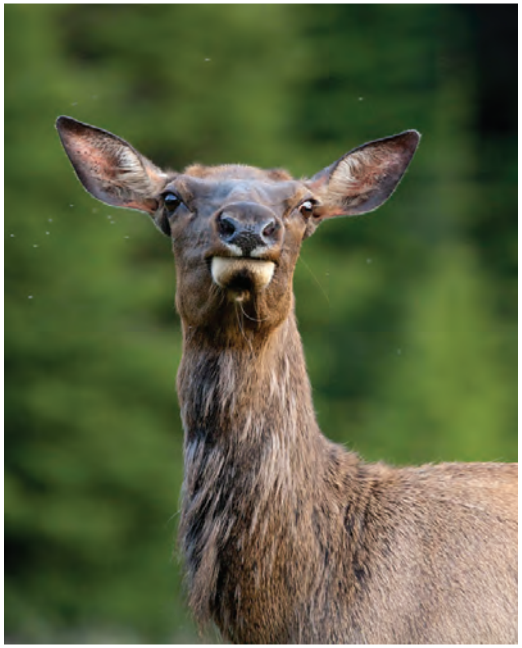
1111 Washington Street SE
Olympia, Washington 98501-1091

wdfw.wa.gov

January 2014

Washington Department of FISH and WILDLIFE

Elk Hoof Disease in Southwest Washington



Sound Stewardship of Fish and Wildlife

wdfw.wa.gov

Elk Hoof Disease
Frequently Asked Questions

What causes Elk Hoof Disease?

Preliminary evidence points to a type of bacteria associated with hoof disease in domestic sheep and cattle. It is likely that these bacteria persist in moist soil. Additional testing is being done to further understand the cause.

There is no scientific evidence that herbicides, such as those used by timber companies, cause this disease, and no link has been made between herbicides and hoof disease in any species that we are aware of. The University of Alberta and the National Council for Air and Stream Improvement are examining characteristics of the habitat used by elk, including industrial timberlands in Southwest Washington, which may add to our knowledge.

How is the disease transmitted?

Scientists do not know for certain how the disease is transmitted. However, they believe infected animals may carry the bacteria to new areas on their hooves, where the bacteria survive in moist soil until infecting the hooves of other animals.

Where in the state does it occur?

WDFW has received sporadic reports from observers in the Cowlitz River Basin of southwest Washington since the mid-1990s. Since 2008, reports have increased and spread west to Pacific County, north to Lewis County and south to Clark County. Due to the rapid increase in observations since 2008, scientists believe a new disease may have entered the elk population at that time, different from the ones responsible for earlier reports.

Is there any treatment for the disease?

Once the disease is present in an elk herd, it is very difficult to eradicate it and the challenge becomes how to minimize its effect. Similar diseases in domestic animals are treated by moving the animal to a clean dry area, aggressively cleaning and paring out the infected part of the hoof, applying topical antibiotics and sometimes a bandage to the affected hoof, administering injectable antibiotics, and forcing the animals to walk through medicated foot baths. But even after receiving such treatments, many animals remain persistently infected. Some initially respond to treatment, only to become re-infected later. Most experts recommend these animals be sent to slaughter.

Can we give the elk antibiotic injections or medicated feed?

Injections may be possible, but first WDFW must identify the cause of the condition and find an effective treatment and dosage. If an effective treatment does not exist, it could take years to develop.

Even if an effective treatment is found, applying it to wild animals across a broad landscape may present an even bigger challenge. For example, untreated animals could continue to infect others. Also, it is likely that treated animals would eventually become re-infected if a causative bacterium persists in the soil. The idea of vaccinating healthy wild animals to prevent them from contracting the disease presents many of the same challenges.

Would using mineral blocks or supplemental feed help?

Good nutrition and trace minerals such as copper, selenium, and zinc are known to be good for domestic animals, but they would not likely prevent or cure hoof disease in elk. Further, providing mineral blocks or supplemental feed could cause elk to congregate at higher densities, promoting conditions that facilitate transmission of the disease.

Is the disease contagious to other animals or humans?

We do not know whether elk hoof disease can be transmitted to domestic animals. Veterinarians from southwest Washington say they have not seen increases in diseases in domestic animals that might be associated with hoof disease in elk.

There is no reason to believe that elk hoof disease is contagious to humans. Similar diseases in livestock do not affect humans. Hundreds of elk have been harvested in SW Washington since the disease first appeared in 2008, and WDFW is not aware of any cases of human disease that have been associated with hoof disease in elk.

Is the meat from affected elk safe to eat?

Microscopic examination of tissues, including meat, from elk affected by hoof disease has not revealed evidence of infection, inflammation, or any other indication that the meat is unsuitable for human consumption. In all animals inspected to date, the disease has been limited to the hooves, and the meat has been normal.

Domestic animals that are severely affected by hoof disease are commonly slaughtered, and hoof disease in domestic animals does not cause federal meat inspectors to condemn the meat as unsuitable for human food. If the meat looks and smells normal, and if common sense and good hygiene are practiced during the harvesting, processing and cooking, the meat is most likely safe to eat.

Can I get a new tag if I harvest an animal with hoof disease?

No. Since all evidence to date indicates that the meat of elk with hoof disease is not affected by the condition, WDFW will not provide replacement tags.

How can hunters and other members of the public help?

Hunters can help WDFW track elk hoof disease by reporting observations of affected and unaffected elk on the department's online reporting form: http://wdfw.wa.gov/conservation/health/hoof_disease/reporting/index.html. If you hike or drive off-road in the known affected area, you can help minimize the risk of spreading the disease to new areas by thoroughly removing all mud from your tires and shoes before leaving the area.

What should I do if I harvest an elk with hoof disease?

Remove the feet and field dress the animal as you normally would. Since this disease may be transmissible to other susceptible animals via infected hooves, please leave the hooves where you killed the animal. Do not transport the hooves outside of the affected area.

Gary A. Wobeser

Disease in Wild Animals
Investigation and Management

2nd Edition

With 17 Figures

Springer

Prof. Dr. Gary A. Wobeser
Department of Veterinary Pathology
Western College of Veterinary Medicine
University of Saskatchewan
52 Campus Drive
Saskatoon, Saskatchewan, S7N 5B4
Canada
e-mail: gary.wobeser@usask.ca

The first edition "Investigation and Management of Disease in Wild Animals" (ISBN 0-306-44703-7) was published by Plenum Press, New York, 1994.

ISBN 978-3-642-08030-2 e-ISBN 978-3-540-48978-8

Springer is a part of Springer Science+Business Media

springer.com

Editor: Dr. Dieter Czeschlik, Heideiberg, Germany
Desk editor: Dr. Andrea Schlitzberger, Heidelberg, Germany
Cover design: WMXDesign GmbH, Heidelberg, Germany

Preface

This book arose out of teaching graduate and undergraduate classes in wildlife diseases. It, in some ways, chronicles my involvement in the investigation and diagnosis of diseases in free-ranging wildlife, primarily in western and northern Canada, since the 1960s. It also, perhaps, reflects the development of wildlife disease study as a discipline. Much of the earlier work in this field was purely descriptive, documenting the occurrence of various diseases in wild animals. I have chosen to retain references to some older and obscure information in this second edition because this body of work provides the foundation for a more analytical approach. The literature on health problems in free-ranging animals is expanding rapidly. I am gratified that the theoretical and quantitative aspects of wildlife disease are receiving more attention than in the past, and that role of disease as a factor in population biology is being analyzed. My hope for the first edition of this book was that it would serve as an overview of the study of disease in wild animals and of methods that might be used to manage health problem. It was, and is, not intended to be a how-to book or an encyclopedic reference to the literature on disease; rather it is intended as a seed crystal around which the reader can build. The inquiries I have received about a second edition suggest that it has been useful. The field of wildlife diseases is an interface area between medicine and applied biology. During the past half-century, medical science has become preoccupied with technology and with dissecting disease phenomena at the molecular level in the laboratory. This has resulted in marvelous tools for the study of disease agents. However, study of disease in whole animals and of the population biology of disease became unfashionable, even though such knowledge is essential if the results of high-tech research are to be applied. In contrast, wildlife biology is concerned with populations and, to the wildlife manager, disease is important only when it has an impact on the population. Some basic concepts of epidemiology, such as mortality rate and survival rate of a population, are used more frequently by the average biologist than by the average health practitioner. Medical scientists don't think of disease in terms of fitness, trade-offs or compensation, but these concepts are fundamental to the ecologist. The role of the "wildlife disease specialist" is to use the tools of biomedical science within an ecological framework to understand how and why disease occurs in free-living populations and when and how it might be managed.

10 Disease management—general principles

> *"The last century was one of triumphs and failures. The triumphs came mostly in the first 70 years of the 20th century: they resulted primarily from understanding the ecology of certain diseases through field and laboratory research and then using that knowledge to develop and implement prevention and control programs aimed at breaking the transmission cycles at their weakest points. The failures occurred when we became complacent after successes were achieved and relied too much on the 'quick fix' or the 'magic bullet' approach to disease control"*
>
> (Gubler 2001)

Discussion to this point has dealt with investigation of disease in wild animals. One basic reason for studying disease is to assess its significance and, if necessary, to identify methods by which the disease might be influenced in a manner considered to be beneficial. If we distill disease management to its most basic form, there are only two options: reduce exposure of the animals to the causative agent or factor, or reduce the effect of the factor or agent on the animals (in some instances, such as the introduction of myxomatosis and rabbit hemorrhagic disease into Australia, the opposite effect may be desired). The remainder of this book will deal with methods for the management of disease in free-ranging animals, and management will be considered in the sense of to restrict or to curb the occurrence or the effects of disease.

10.1 Is management desirable?

A question that must be dealt with immediately is the philosophical and ecological desirability of attempting any type of disease management in free-ranging wild animals. All disease in free-living animals is considered by some people to be a natural phenomenon that contributes to the 'balance of nature'. Marcogliese (2005) presents reasoned arguments that support the view that "*healthy ecosystems have healthy parasites*" and Horwitz and Wilcox (2005) note that "*parasitism is not simply a pathogenic relationship requiring treatment, but rather a process that through multiple agencies contributes to within and between species diversity, community structure and diversity, and therefore the ability of organisms to respond to change*". This point of view reveals a clear difference between the way disease is viewed in humans and domestic animals on one hand, and in wild species on the other. Very few people would argue that smallpox or other great plagues should be allowed to run their course in human populations, although these diseases may be powerful selective forces for the continued evolution of our species. To allow some of these diseases to go unchallenged, when we have the capacity to influence their course, would be to promote selective genocide of those in less developed parts of the world. Similarly, there is little sentiment for allowing foot-and-mouth disease to become established in North American cattle or to leave pet dogs unprotected by vaccination against canine distemper. In contrast, attempts to manipulate disease in wild species may be viewed as unnatural interference. If we accept this reasoning, an investigator may be motivated by a sense of curiosity to study the role of disease in the population biology of a species, but should not intervene to change the course of the disease. In considering this question, we should examine the rationale for disease management. The reasons for undertaking any type of disease manipulation in wild animals are essentially anthropocentric, i.e., management is usually done to benefit humans in some way. Since this is the case, a hands-off approach may be entirely appropriate where the consequences of disease are perceived to be of little or no consequence, and we can act as disinterested observers of what happens to the animals. This approach would be even more appropriate if the animals were unaffected by human activities and lived in a pristine environment where disease was a truly natural event. Undoubtedly, disease in the general sense is a natural phenomenon and animals became sick and died of a variety of diseases under pristine environmental conditions. However, **every** wild animal now lives in an environment modified to some degree by humans. Many of the environmental changes that have occurred have been undesirable and have altered both the type and manner in which disease occurs. For example, the enhanced accumulation of cadmium in the organs of wild moose as a result of acid precipitation (Froslie et al. 1986; Borg 1987), selenium poisoning of water birds using irrigation runoff water (Ohlendorf et al. 1988), and the introduction of exotic diseases such as avian malaria to Hawaii (Warner 1968; Van Riper et al. 1986), trichomoniasis to the Galapagos Islands (Harmon et al. 1987), *Elaphostrongylus rangiferi* into caribou in Newfoundland (Lankester and Northcott 1979), and West Nile virus to North America are not natural events. Each of these resulted from human activities. If one appraises the situation critically, most disease-management activities in wildlife are actually exercises in mitigation. The manager usually is trying to soften or reduce the effect of some other human activity.

As the amount of natural habitat available for wild animals has decreased, the impact of humans on wild species has increased. The last half of the 20th century saw "*the most rapid period of large scale ecological transformation in human history*", with "*the disassembly of orderly natural communities*" (Wilcox and Gubler 2005). For some wild animals, the intensity and the level of sophistication of management have also increased remarkably during this period. This is perhaps most evident for wild waterfowl in North America. Many wild ducks are now hatched in nests on artificially created islands or in artificial nesting structures located on wetlands created by damming runoff water from agricultural land or urban areas. The mallard, northern pintail and Canada goose (as well as many other species) derive a substantial part of their nutrition from agricultural crops, and special feeding sites or lure crops are used to concentrate the birds and reduce their depredation on farmers' fields. Many individuals of some waterfowl species begin life in an incubator or captive facility and then are released to the wild to 'supplement' natural reproduction. The birds face human-made hazards, such as pesticides, overhead wires, domestic pets and hunting regularly. They winter on intensively managed refuge areas that promote the artificial concentration of large numbers of birds on small areas for a prolonged period of time. Such circumstances can hardly be considered natural. Disease management may need to be a part of the integrated management of these species, in the same way that disease management is an integral part of intensive animal agriculture. The need for disease management is even more evident for endangered or threatened species where a single disease occurrence could extirpate the remnant population and where managers are forced into the use of practices such as translocation and captive breeding, which enhance the probability of disease occurrence. Leopold (1939) left little doubt of his opinion of the importance of disease control when he included a chapter on the subject in his seminal book on wildlife management and stated: "*In its more advanced stages, game management is in effect the art of maintaining a population which is vigorous and healthy in spite of its density*". What is needed is management that is based on an understanding of ecosystem level changes caused by humans and that seeks to reduce but not over-control the effect of disease agents (Horowitz and Wilcox 2005).

10.2 Is management feasible?

A second basic question that needs to be addressed is the feasibility of management of disease in wild animals. If management is impractical, there is no benefit in proceeding further with this discussion. Skeptics sometimes dismiss the study of disease in wildlife as an interesting but esoteric pursuit because, as has been stated to me: "*even if you find a disease you can't do anything about it*". This attitude is largely a result of tunnel vision, in which disease management is perceived to occur only through the medication and treatment of sick individuals. The skeptic "*overlooks the obvious fact that "doctoring" is of recessive importance in health control, even in domestic species and man*" and that "*the real determinants of disease mortality are the environment and the population*" (Leopold 1939). Treatment of sick individuals and immunization are important components of human and veterinary medicine, but most of the real advances in general health of both humans and domestic animals are attributable to management of environmental factors, such as nutrition, provision of safe drinking water, adequate shelter and sanitation, and through regulation of population density. The best proof of this is the rapid deterioration of health and the emergence of pestilence that occurs in human populations in time of war, when there is environmental and social disruption. Similarly, most disease problems in livestock occur among overcrowded, poorly managed animals. Environmental and population factors that influence disease can be manipulated in wild animal populations and wild animals "*are being "doctored" daily, for better or for worse, by gun and axe, and by fire and plow*" (Leopold 1939), but it is interesting that improved sanitation, nutrition, and provision of clean water seldom have been included as part of disease management in wild animals.

A basic feature that affects the feasibility of management is the ability to detect and monitor changes in the occurrence of disease. There are many aspects to detection including:

- how quickly will a new disease be detected?
- how far will it have spread and how entrenched will it be before it is detected?
- how accurately can the disease be detected in the individual animal, i.e. how sensitive and specific are the tests, and how wide are the confidence interval about estimates?
- what proportion of the population can be monitored?
- how often can the population be monitored?

10.3 Who is management for?

If one can decide that management of a disease is acceptable and at least potentially possible the next step is to assess whether or not it is needed, i.e., why is the program being undertaken? As noted earlier, the rationale for disease management is almost always based on an anthropocentric view of the world and the three major reasons advanced for management of disease in wild animals are that the: (i) presence of disease in wild animals is a threat to human health, (ii) presence of disease in wild animals is a threat to the health of domestic animals, (iii) disease is having a significant deleterious effect on the population of a wild species considered beneficial to man. I placed these three reasons in this order intentionally, because it represents the real world priority for disease management in wild animals. There is more interest in the role of wild animals in human disease at present than at any time in the past, because of the global problem of emerging infectious diseases in humans. Most of these diseases are zoonoses and many are associated with wild species.

It is very important at the outset of any proposed management program to identify the **target population**, i.e., "*the population of concern or interest*" (Haydon et al. 2002). For most zoonotic diseases, the target species is *Homo sapiens*. The billions of dollars that have been spent worldwide to manage rabies in wild carnivores have been committed to protect humans and not to benefit foxes or raccoons. In other situations, domestic animals are the target, e.g., management of bovine tuberculosis in badgers, brushtail possums and white-tailed deer is done for the benefit of cattle (and humans) and not for the wild species. Occasionally a wild species may be the target population; for example, programs to vaccinate domestic dogs have been designed to protect the Ethiopian wolf from shared diseases (Laurenson et al. 1998). Identification of the target species is important because the ultimate success of any management program must be based on the effect on the target species. For instance, a program that reduced the prevalence of tuberculosis in deer in an area but did not reduce the incidence of the disease in cattle would not be considered a success.

Disease management might be attempted for other reasons, such as when disease decreases the value of a wild species for human use, e.g., when the presence of parasites makes game meat aesthetically unpleasing, or when a skin disease mars the value of the pelt of a fur-bearer; when the occurrence of disease creates a nuisance factor or raises concern among the general public; or when the presence of a condition in wild animals indicates a degree of environmental degradation that is unacceptable for human health. In the latter instance, the wild species acts as an unintentional monitor of overall environmental health. The assessment of the risk from disease in each of these situations (threat to human health, threat to domestic animals, or negative effect on the population of wild animals) requires detailed quantitative information on the occurrence and effect of the disease in the wild population, and of the probability of spread from the wild animals to humans and/or livestock, where appropriate. This, in turn, requires that there are accurate methods for diagnosing the disease, and for surveillance of the disease agent and of its effects in all relevant populations.

It is usually much easier to define (and defend) the rationale for management of a disease that affects human or livestock health than it is for diseases that are restricted to wild animals. This partially reflects the difficulty in assessing the population effect of disease in wild animals. In some instances, such as catastrophic die-offs that have occurred in bighorn sheep throughout North America, it may be relatively easy to demonstrate a need for management. But, when biologists cannot agree if the effect of hunting and natural mortality on waterfowl populations are additive or compensatory (Johnson et al. 1997; Pöysä et al. 2004), it will be very difficult to prove that management of a disease, such as botulism, on a single marsh would have any detectable effect on the overall population (although it might be important for a local segment of the population). Samuel (1992) presents a good discussion of the difficulty in assessing the effect of disease on a waterfowl population.

10.4 Costs and benefits of management

Discussion of the rationale for any disease-management program should include some type of benefit:cost analysis. This analysis should include consideration of the relative merit of various methods of meeting the same objective. Consider a marsh in which botulism kills a number of ducks every year. The overall objective of the waterfowl manager responsible for this marsh might be to produce more ducks, and the measurable end-product of his efforts is the number of ducks that are alive in the autumn. Among the strategies available to the manager to meet this objective are to: (i) increase natality (i.e., produce more ducklings and accept that a proportion of these will die of botulism), (ii) to reduce mortality to all causes, including botulism, or (iii) some combination of (i) and (ii). The cost of various types of management to increase waterfowl production, such as through construction of nesting islands and nesting structures, and of methods to reduce mortality as a result of predation, have been estimated in terms of dollars per duckling produced (Lokemoen 1984; Chouinard et al. 2005). I am not aware of any similar attempt to estimate the value of a mallard saved from botulism, either through treatment of sick birds or preventive management. This type of analysis will be necessary if disease management is to be accepted as a valuable practice.

Assessment of the costs of management must go beyond the short-term monetary costs and must consider long-term ecologic costs and benefits that may result from management (many of these may be unexpected and, hence, impossible to assess in advance). Examples of potential long-term costs include: (i) development of resistance to treatment as a result of the intense selection pressure placed on a disease agent (treatment may be successful in the short-term, but fail in the long-term, and resistance may be to more than one therapy or treatment); (ii) development of resistance in species other than the one being managed, so that new problems emerge; (iii) loss of components from the environment, such as predators and parasites that limit the abundance of the disease agent, so that the population of disease agents increases; (iv) selection for new dispersal and transmission methods that allow the agent to find hosts; and (v) changes in abundance of a species as a result of removal of one disease as a limiting factor, that allow emergence of other disease problems. As an example of the last point, fox populations have increased dramatically across Europe and foxes have become common in urban environments, at least partially because of elimination of rabies by vaccination (Chautan et al. 2000). This has resulted in emergence of *Echinococcus multilocularis* as an important zoonosis (Sréter et al. 2003) and the increased fox population also has raised concerns that if rabies reappears there may be larger and more intense epizootics (Smith and Wilkinson 2003).

10.5 How will management be done?

Selection of the most appropriate method for management requires a clear understanding of the cause and ecology of the disease and of both the course of the disease in the individual and the biology of the disease within the population. Disease management can be viewed as a tactical battle in which one uses intelligence gathered about the disease to identify the most vulnerable point at which to attack. The soft underbelly of infectious diseases is often in the method of transmission and many techniques are designed to interrupt the process or to prevent contact between agent/causative factor and host.

In every disease-management scheme it is imperative to identify all the players and to clarify their role. We have already discussed the need to identify the target species for whom the management is being done. In non-infectious diseases, such as intoxications caused by environmental contaminants, it usually is relatively easy to identify the species involved and the source of the toxicant, which may be from a discrete point or more diffuse source. The next step is to identify how the material reaches the target and this may involve other species. For example, cadmium poisoning of badgers in the Netherlands involves bioaccumulation of cadmium in earthworms eaten by badgers. The rate at which this bioaccumulation occurs depends upon the soil pH, which is influenced by acid precipitation (Klok et al. 2000). In some infectious diseases, only the target species is involved and in these it may be possible to manage the disease without considering other sources. However, most important infectious diseases that involve wild animals involve some source or reservoir outside the target species. The reservoir may be one or more animal species or some abiotic feature of the environment. Haydon et al. (2002) defined a reservoir as: "*one or more epidemiologically connected populations or environments in which the pathogen can be permanently maintained and from which infection is transmitted to the defined target population*". As an example, the reservoir for anthrax is soil, within which *Bacillus anthracis* can persist for years. In some diseases, species other than the target are an obligate part of the life cycle of the disease agent, as is the case with many diseases caused by helminths, arthropods and protozoa. Other species also may be involved in disease transmission without being an obligate part of the agent's life cycle, e.g., pox viruses may be transmitted among birds on the mouthparts of mosquitoes. The alternate or other species may be infected with or without having recognizable disease.

If more than one vertebrate can be infected by a disease agent, the condition is often called a multihost disease. In multihost diseases, it is critical to define the role of each vertebrate host species as an early step in planning management. **Maintenance hosts** are those in which the disease agent is capable of cycling independently within the population in the absence of an external source of infection. **Spillover hosts** are those in which the disease can be transmitted within the population but in which the disease will die out without an external source of infection. **Dead-end hosts** are those in which the disease is not transmitted within the population and all infections result from an external source (Caley et al. 2002). If the objective of management is to reduce transmission of the disease, it is important to direct actions primarily at the maintenance hosts. For example, the nematode *Heterakis gallinarum* is a multihost parasite that occurs in ring-necked pheasants, grey partridge and red-legged partridge. The pheasant is a maintenance host for the worm, while the partridges are spillover hosts, although the grey partridge may be affected severely by the parasite (Tompkins et al. 2002). In this situation, management would be most profitably directed at the infection in pheasants. Feral pigs were found to be a dead-end host for *Mycobacterium bovis* infection in Australia and the prevalence of tuberculosis in pigs declined following destocking of cattle and water buffalo, without any attempt to direct manage the disease in pigs (McInerney et al. 1995). In some situations, management can be directed at preventing exposure of a spillover or dead-end target species to the disease. For instance, humans are a dead-end host for rabies in most situations, but education can be used to reduce exposure of the public to rabid animals that are the maintenance host for the virus.

Even within a single species it is important to identify those individuals that are responsible for most of the transmission, because these are the logical focus for management. Woolhouse et al. (1997) examined a range of infectious diseases and found that "*typically, 20% of the host population contributes at least 80% of the net transmission potential.*" They suggested that management directed at the 20% group is potentially highly effective, while programs that fail to reach all of this group are likely to be much less effective in reducing disease prevalence in a population. The so-called '20/80 rule' appears to apply in several diseases of wild rodents. In yellow-necked mice, sexually mature males with high body mass are the segment of the population responsible for the majority of transmission of tick-borne encephalitis virus infection (Perkins et al. 2003). Adult males also were responsible for most of the transmission of an intestinal nematode in yellow-necked mice (Ferrari et al. 2004). The reservoir for hantavirus infection in rodents is thought to be long-lived, persistently infected individuals, particularly adult males (Calisher et al. 2001). In each of the above examples, adult males appear to be the segment of the population that deserves attention. Skorping and Jensen (2004) went further and suggested that, as a general rule, those interested in disease management in mammals need to look particularly closely at males. Different types of disease demand different strategies. For non-infectious diseases, such as various types of intoxication, management is usually directed at either eliminating the source of the risk factor or at limiting access by animals to the risk factor. The occurrence of many such diseases appears to be relatively independent of host population density.

Management of infectious diseases is complicated by replication of the causative agent, with transmission to other susceptible individuals in the population. An extensive literature has emerged on theoretical aspects of the population biology of infectious diseases. Application of these concepts to disease in wild animals is exemplified in Hudson et al. (2001). The reproductive or transmission success of the agent appears to be central in determining the type of management that may be most appropriate. Often this parameter is expressed as R_0, the basic reproductive rate or number of the disease agent, which measures the inherent transmissibility of the agent (Fraser et al. 2004) and is equivalent to the intrinsic rate of increase (r) in population models. R_0 is not a constant for a particular disease agent; it is determined by features of both the agent and the animal population in which it occurs.

10.5.1 Microparasites and macroparasites

Infectious agents can be divided into two groups on an ecological rather than a taxonomic basis (Anderson and May 1979). **Microparasites** (viruses, bacteria, protozoa) are characterized by small size, short generation time, and the ability to multiply directly and rapidly in the host. **Macroparasites** (helminths, arthropods) have much longer generation times and direct multiplication within the host is absent or occurs at a low rate. The type of disease produced by the two groups is quite different. Microparasites usually produce short-term transient infections (in relation to the life-span of the host) and induce long-lasting immunity to reinfection. Macroparasites produce persistent infections with continual reinfection, and both the immune response and the pathology produced depend on the number of parasites harbored by the host. R_0 for microparasites has been defined as the "*average number of secondary infections attributable to a single infectious case introduced into a fully susceptible population*" (Fine et al. 1982). R_0 for macroparasites is defined as the average number of female offspring that live to reproduce produced by a single female introduced into a completely susceptible population, or "*the number of 'next generation' adult parasites that would arise from one adult parasite in a totally susceptible population*" (Roberts et al. 1995). In either case, when $R_0=1$, an infection is barely able to maintain itself in an enzootic state. If R_0 falls to <1, the incidence of disease will decline, eventually to extinction. The aim of management programs for most infectious diseases is to depress the reproductive rate and, for eradication, it must be reduced and maintained below 1 (Anderson 1982). In general, diseases with a high reproductive potential will be more difficult to control than those with a low R_0 value (Anderson 1982).

The features of micro- and macroparasites may have a great effect on the type of management measure that is most appropriate. For example, immunization may be much more appropriate for the control of a disease caused by a microparasite than for a disease caused by a helminth. In the latter case, management might be directed at decreasing the burden of worms in certain heavily infected individuals in the population, rather than preventing infection. Although the basic reproductive rate is not known for most infectious diseases of wild animals, models have been constructed that estimate threshold populations required for the occurrence of epizootics of certain diseases. For example, the population density of foxes required for maintenance of rabies in some areas of Europe was estimated, on the basis of both epizootiological observations and modeling, to be approximately 1 fox/km^2 (Anderson et al. 1981). Such estimates and the modeling techniques that have developed provide a theoretical basis for planning programs.

10.6 A management matrix

Disease management can have one of three broad objectives: prevention, control, or eradication.

Prevention includes all those measures designed to exclude or prevent the introduction of a disease into unaffected animals or into an unaffected population, and these can be applied at either the individual animal or the population level. Examples range from restrictions on the importation of exotic animals to prevent the introduction of foreign animal diseases such as foot-and-mouth disease into a geographic area, through procedures such as fencing to limit exposure of animals to toxins or infected animals, to protection of animals within a population through immunization.

Control, in the narrow sense, applies to activities designed to reduce the frequency of occurrence or the effects of existing disease within a population to some acceptable, or perhaps more accurately to a tolerable level. Often this level is defined by the funding available for control activities and by a point where the cost of further control outweighs any additional benefit that might be derived. By definition, disease control implies that some level of disease will persist in the population and this means, in most instances, that the control measures will have to be continued in perpetuity with continuing costs.

Eradication involves total elimination of an existing disease and often requires a Herculean effort. The term eradication has been used in many ways. Yekutiel (1980) proposed that eradication is "*the purposeful reduction of specific disease prevalence to the point of continued absence of transmission within a specified area by means of a time-limited campaign*". Ottesen et al. (1998) proposed that eradication is "*Permanent reduction to zero of the worldwide incidence of infection caused by a specific agent as a result of deliberate efforts . . .*" and differentiated this from elimination of disease ("*Reduction to zero of the incidence of a specified disease in a defined geographic area . . .*") and elimination of infection ("*Reduction to zero of the incidence caused by a specific agent in a defined geographic area. . . .*"). The definition by Yekutiel is appropriate for our purposes because it includes the elements of space and time. Only one infectious disease (smallpox) has been completely extinguished as a free-living agent as a result of a management program; however, many diseases have been eradicated on a regional basis. Eradication usually is contemplated only for the most serious of diseases, but there have been successful localized disease eradication programs in wild animals. Foot-and-mouth disease was successfully eradicated from deer in California in 1923 (Brooksby 1968) and mercury poisoning of birds (associated with the use of alkyl-mercurial seed-dressing agents) was eliminated from Sweden (Wanntorp et al. 1967). The present effort to eliminate the use of lead shot for waterfowl hunting in many areas of the world is an attempt to eradicate lead poisoning in wild waterfowl. Eradication programs have a finite end-point and, if accomplished, the emphasis usually shifts to prevention of reestablishment of the disease, without the recurrent costs for control.

The choice among these three basic techniques depends upon many factors including the presence or absence of the disease in the area, the length of time the disease has been present, the frequency of occurrence and distribution of the disease, the species affected, the availability of suitable methods for detection, diagnosis and management, the desirability or need for management, and the ability to convince others of this need. Often an overall program may involve aspects of prevention, control and eradication, with different techniques being used at various stages of the program.

Management may be attempted through manipulation of any of the three basic determinants of disease: the agent, the host, or the environment. Influencing human activities may be considered as management of the host or environment, depending upon the features of the disease. If we combine the three objectives mentioned earlier with these three potential sites for manipulation, we can construct a matrix of management possibilities:

	Agent	Host	Environment
Prevent			
Control			
Eradicate			

Some agents or risk factors can be prevented entry to an area, and other risk factors, such as certain toxins, may be reduced or eliminated. The host population may be manipulated through reduction of population density, dispersal from areas where the disease occurs, or by increasing the resistance of individual animals through immunization, improved nutrition, or by therapy of diseased individuals. The most extreme example of host manipulation is complete depopulation of a host species for disease control. There is an endless variety of ways in which environmental factors may be manipulated to effect disease; the most important of these for management of wildlife diseases are likely to be through management of human activities.

10.7 How far will the program be taken?

The objective in prevention programs is often total absence of disease from an area. There must be continual surveillance to ensure that the disease has not been introduced or become re-established, negating the effort spent in prevention or eradication. In most control programs, the objective is to reduce the occurrence or effect of the disease, rather than to eliminate it completely. Each program of this type should have a clearly defined objective, e.g., to reduce the prevalence of the disease to less than 10%, or to immunize at least 70% of the animals in the population. For this to be done, the prevalence or severity of the disease must be known prior to the onset of any control, and there must be continual surveillance to monitor the effect of the control program. Choice of a suitable end-point for control may involve some type of benefit:cost analysis and there may be a level of disease below which the cost of further control is greater than the benefit received.

In the case of disease eradication, the objective is total elimination of the disease from the area and the program must be continued until that end is accomplished. A potential problem in eradication programs is that when a disease has been reduced to a very low prevalence in the population, it may be extremely difficult to determine if the disease has in fact disappeared (sampling methods and minimum sample size required if one wishes to have confidence in the absence of disease in a population were discussed in Chap. 7). Criteria developed for evaluating the feasibility of eradicating vertebrate pests (Bomford and O'Brien 1995) are relevant in considering eradication of a disease. These (with modification) include that:

- the rate of removal (of the agent) must exceed the rate of increase.
- immigration of the agent must be prevented.
- all reproductive members of the population must be at risk of removal.
- it must be possible to detect the agent or disease at low prevalence (if it cannot be detected at low prevalence it will be impossible to know if eradication is successful).
- benefit/cost analysis favors eradication over control.
- there must be a suitable socio-political environment.

Bomford and O'Brien (1995) indicated that a negative in any of the first three criteria dooms eradication, and a negative in any of the latter three criteria greatly reduces the feasibility of eradication. Availability of effective intervention to interrupt transmission of the agent and practical diagnostic tools with sufficient sensitivity and specificity are essential elements for eradication to succeed (Ottesen et al. 1998). The potential to eradicate a human disease depends upon humans being essential for the life cycle of the agent, the agent having no other vertebrate reservoir, and the agent not amplifying in the environment (Ottesen et al. 1998).

10.8 How will success be measured?

The final factor that must be considered before starting any program is how the effectiveness of the procedure will be measured. Each management program should contain a predetermined method for assessing its efficacy. This seldom has been done in wildlife disease work. For instance, collection and disposal of carcasses has been a standard technique used for many years during outbreaks of avian cholera, botulism, and duck plague in wild waterfowl. Although it seems intuitively correct to remove carcasses and, hence, decrease the amount of infective or toxic material in the area, I am aware of only one study that attempted to determine if carcass removal had a significant effect on the outcome of an outbreak, although the costs may be very substantial. Evelsizer (2002) found that collection of carcasses had no significant effect on the mortality rate of moulting ducks during botulism outbreaks on wetlands in Saskatchewan, although resource agencies had been spending approximately $1 million/year picking up duck carcasses in western Canada. The conflicting reports by Pursglove et al. (1976) and Montgomery et al. (1979) provide an interesting example of the difficulty in assessing the efficacy of a program, when no method was established for doing so in advance of the action. Pursglove et al. (1976) concluded that "*depopulation*" of more than 6,000 American coots resulted in the termination of an avian cholera outbreak, while Montgomery et al. (1979) concluded that the decline in mortality in a similar outbreak (in which no action was taken) was the result of "*thinning of the bird population in the area as a result of both the disease process and spring migration*". A small experimental study of treatment of nematode infection in rodents demonstrates the need for monitoring to determine if the methodology is successful. Ferrari et al. (2004) treated yellow-necked mice with an anthelmintic. When only females were treated, the prevalence of worms in females declined about 10% but there was no change in the prevalence in males. However, when males were treated, the prevalence and the average number of parasite eggs declined significantly in both sexes. In this case, monitoring indicated the most effective form of management.

Monitoring the efficacy of management, as it proceeds, can be very important for improving the method. Continuous monitoring and accurate diagnosis are essential for assessing the efficacy of a program. If several agents produce a similar clinical disease, there may be efficient control of one of the factors, but there may be little evident effect on the overall clinical disease occurrence. In such situations, there may be an unjustified loss of faith in the management procedure because of an inability to see results.

Disease-management programs often involve a combination of methods, and the approach must be sufficiently flexible to allow change as the process proceeds. The prevalence of disease may change, new factors may be introduced or discovered, and economic and political realities may vary. It is often difficult to maintain enthusiasm for a program over an extended period unless there is clear evidence that it is successful, and even if the program is successful, the reduced visibility of the disease may result in diversion of effort to other apparently more pressing problems. In disease-control programs "*success often breeds failure*", because relaxation of effort in the later stages of a program may lead to recrudescence of an apparently vanquished disease that "*will return with a vengeance* (Gubler 2001)". As in any other scientific endeavor, the rationale, objectives, methods, and results of all activities should be carefully recorded, so that one can benefit from past experience. The chapters that follow will deal with specific techniques for disease management in free-ranging animals, using examples, some of which were successful! As a final thought, it appears that in general, it is much easier to prevent the introduction of a new disease into an area than it is to control or eradicate an established disease. This thought should be uppermost in the mind of every wildlife manager whenever the translocation of animals or other management that might influence the occurrence of disease is contemplated.

10.9 Summary

- Wild animals live in environments modified by humans. Most attempts to manage disease in wild animals are necessary because of, or are undertaken to mitigate, the effects of other human activities.
- Management is done because the presence of disease in wild animals is considered a threat to human or domestic animal health, or less commonly to alleviate negative effects of disease on populations of desirable wild species.
- Disease management can have one of three basic objectives: prevention, control, or eradication. Prevention involves precluding the occurrence of disease in animals or populations where it does not already occur. Control involves reducing the frequency of occurrence or the severity of existing disease. Eradication involves total extirpation of a disease from an area or population.
- Management may be attempted by manipulating the agent (risk factor), the host population, the environment (including human activities), or by combinations of these methods. A detailed knowledge of the ecology of the disease is required in choosing the most appropriate method.
- Every disease-management program must have a clear rationale, objective and plan of action, as well as a predetermined method for assessing its efficacy.

11 Management of the causative agent/factor or its vector

The most direct method of managing a disease is to eliminate its cause. The basic requirements for management through affecting the agent directly are: (i) a knowledge of the cause, and (ii) some method for its reduction or elimination. The simplest method of eliminating a causative factor is to prevent the introduction of new disease agents into areas where they currently do not exist. In practice, this form of disease prevention usually involves restricting or modifying human activities, rather than physically barring entry of the agent, and it will be discussed in Chap. 15, together with other methods based on influencing human activities.

The term eradication is often used in disease-management programs directed against the agent and this word must be defined carefully because it has been used in many different ways (Yekutiel 1980). In most cases, when eradication is considered, what is intended is elimination of the agent from a defined area, rather than its total extinction. Often, all that is required for effective disease management is reduction of the agent to a level at which its effects become negligible or at least tolerable. It is incorrect to describe such a program as a disease eradication effort and we should more correctly speak of disease control. The discussion that follows will deal with both infectious and non-infectious diseases. While it is dangerous to generalize, non-infectious diseases, such as those resulting from various poisons and toxins, often are technically easier to control than are diseases caused by infectious agents. The major difference between the two groups is the property of reproduction by infectious agents. If a quantity of a toxic material is released into the environment, it will eventually disappear within some finite time, although this period may be extremely long in the case of persistent agents, such as the polychlorinated biphenyls. In contrast, if a finite amount of a new virus or other infectious agent is introduced into a population, the agent may increase in amount and persist indefinitely through continuous replication. In the case of a toxin, management can be directed primarily at preventing the release of additional material into the environment; in the knowledge that the amount already present will disappear spontaneously over time. The disappearance process might be accelerated by management that physically removes the