

ASSESSING FUTURE THREATS TO THE JACKSON, WYOMING/ NATIONAL
ELK REFUGE SOCIAL-ECOLOGICAL SYSTEM:
A SCENARIO PLANNING CASE STUDY

by

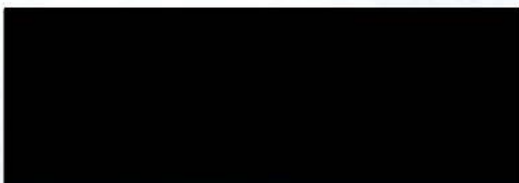
MARK WILLIAM NEFF

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Dr. Peter A. Walker, Chair of the Examining Committee

5/31/05

Date

Committee in Charge:

Dr. Peter A. Walker, Chair
Dr. Richard D. Margerum

Accepted by:



Dean of the Graduate School

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Mark William Neff

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Scenario planning has been used for several decades by the military and industry to systematically address long-term uncertainty, and there is a growing precedent for utilizing the technique for making ecosystem management decisions. This thesis employs a scenario planning technique to investigate two key uncertainties in the Jackson, Wyoming/ National Elk Refuge social-ecological system: the ecological and economic effects of wildlife disease and wolf recolonization. The local economy is dependent on elk for tourism and hunting, creating a close link between the social and ecological systems. The current elk management regime utilizes ranching techniques such as artificial feeding and vaccination to create large herds despite a paucity of winter range. There is an ongoing NEPA analysis to consider alternatives to the feeding programs currently in place. I present four storylines portraying plausible future conditions to help managers and stakeholders consider long-term variability and potential vulnerabilities when making management decisions.

CURRICULUM VITAE

NAME OF AUTHOR: Mark Neff

PLACE OF BIRTH: Denver, Colorado

DATE OF BIRTH: January 30, 1977

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon
Whitman College

DEGREES AWARDED:

Master of Science in Environmental Studies, 2005, University of Oregon
Bachelor of Arts in Foreign Languages and Literatures: German, 1999,
Whitman College

AREAS OF SPECIAL INTEREST:

Ecology
Human Dimensions of Biology
Nature-Society Relations
Science Studies

PROFESSIONAL EXPERIENCE:

Graduate Teaching Fellow, Environmental Studies Program, University of
Oregon, Eugene, 2003-2005

Research Intern, Jackson Hole Conservation Alliance, Jackson, Wyoming, 2002-
2003

Research Assistant II & Lab Manager, Oregon Health Sciences University,
Portland, Oregon, 1999-2000

GRANTS, AWARDS AND HONORS:

Travel Grant to present at Emerging Issues at Urban/Rural Interfaces: Linking
Science and Society, National Science Foundation, 2005

PUBLICATIONS:

- Harding, Cary O., Mark Neff, Kelly Jones, Krzysztof Wild, and Jon A. Wolff.
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Does Not Correct Hyperphenylalaninemia in PAH^{Enu2} Mice." *The Journal of
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Administered Tetrahydrobiopterin and Its Implications for Heterologous Gene
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CHAPTER I

INTRODUCTION

The study area for this thesis is the National Elk Refuge and the adjacent private land, both of which are in Teton County, Wyoming (see *Figure 1 Study area and the Greater Yellowstone Ecosystem*). The field area is in the center of the Greater Yellowstone Ecosystem, considered to be one of the most in-tact ecosystems in the 48 conterminous states (Smith et al. 2003).

Jackson, Wyoming is a community with an evolving economic structure: the region is now dominated by year-round tourism whereas it was formerly a ranching economy. Hunting has remained a significant part of the economy. These three industries that comprise the majority of the economy have competing claims on the region's abundant wildlife resources and differing ideas as to how the wildlife should be managed. The current management regime, wherein elk and bison are fed to maintain large herds despite diminished winter range, creates a large and visible elk herd – a boon to the hunting and tourism industries. The feeding program, however, creates conditions that encourage wildlife disease on the National Elk Refuge (NER) and other local feedgrounds. The fed elk herds are a reservoir for the bacterial disease brucellosis, a disease ranchers perceive to be a significant threat their industry. Competing claims on elk have led to a series of lawsuits between the state of Wyoming and the federal government over the right to make management decisions for the animals which reside on a national wildlife refuge that lies within Wyoming's borders. Resulting from a political compromise, in 2003 Wyoming began vaccinating elk on the refuge against brucellosis with a cattle vaccine that the state insists is efficacious in elk, but which is deemed by the US Fish and Wildlife Service to be only marginally effective.

Elk management is contentious because the stakeholders have competing needs and exert pressure on decision makers to ensure their needs and opinions are addressed. Tim Clark argues that: "Since goals for management of the Jackson Hole elk herd have not been agreed upon and since problems are defined only in relation to goals, different agencies and interest groups see different problems"(Clark 2000: 172). Hunter and outfitter groups wish to maintain the feeding program because it leads to large elk herds that must be culled by a yearly hunt to keep the population down. If vaccination is perceived as a way to maintain large herds, they support that (Kahn 2000). Ranchers support feeding on the refuge because it prevents elk from foraging on their lands. Cattle ranchers have had significant economic incentive to support elk vaccination because of a perceived possibility that elk could transmit brucellosis back to cattle, the original host of the disease (Kahn 2000). Cattle in Wyoming were recently diagnosed with brucellosis, causing the US Department of Agriculture to revoke their brucellosis-free status and mandate restrictions on interstate cattle shipments. The Wyoming Agriculture Department Director John Etchepare estimated that brucellosis testing, mandated by the Animal and Plant Health Inspection Service (the federal agency responsible for livestock brucellosis management) when the state lost its brucellosis-free status, could cost Wyoming ranchers as much as \$1.6 million per year (Black 2004). Ranching groups support vaccinating the elk because they perceive it as being a step towards eradication of the disease. Interestingly, the elk deemed to be the source of infection for the diseased cattle that caused the state to lose its brucellosis class-free status were vaccinated on a Wyoming Game and Fish Department feed ground (Wyoming Brucellosis Coordination Team Report & Recommendations 2005).

The elk feeding program benefits a number of stakeholders; it supplies hunters with abundant elk, tourists with world class wildlife watching opportunities from the town of Jackson, and provides the townspeople with a sense of pride in their wildlife herds. On the other hand, feeding creates conditions ideal for brucellosis and other diseases. Some stakeholder groups are opposed to aspects of the current management regime because of diseases the artificially dense herd supports or could potentially support. Others disagree with intensive management in a region perceived to be largely wild. H Bradley Kahn

identified a list of twenty stakeholder groups who are interested in management issues on the refuge, including: state and federal governmental agencies; the U.S. Department of Agriculture's Animal and Plant Health Inspection Service; hunting, ranching, and environmental advocacy groups, tourists, Native Americans, and others (Kahn 2000). Despite its impressive length, this list is not comprehensive. Each of these groups has vested interest in the elk and their well being, but each defines a healthy elk herd in its own manner. In so doing, each group frames management debates in terms of how changes will affect them. As Kahn argues: "Like all natural resource management, managing elk can be reduced to questions of 'How will they be used?' and 'Who gets to decide?'" (Kahn 2000: 171) Any proposed change in management strategies will likely benefit some constituencies and come at an expense to others. The feeding program meets the needs of some stakeholders, but it creates conditions that encourage wildlife diseases. The brucellosis vaccination program is extremely contentious because of its questionable efficacy, but it has political value whether or not it is effective.

Brucellosis is only minimally harmful to the overall elk population; the herd has been above target size for years despite the brucellosis epidemic. This disease is not a threat to the ecosystem. Some researchers believe, however, that the presence of brucellosis on Wyoming feedgrounds is a biological "red flag" indicating that the feeding programs create artificially dense elk populations conducive to disease outbreaks and making the herds more vulnerable to other wildlife diseases (Smith 2001). More insidious diseases, such as bovine tuberculosis and chronic wasting disease, have the potential to adversely affect the elk herd and the local economy. The recent decision to vaccinate the herd against brucellosis does nothing to address the crowded conditions that allow the disease to thrive there, but rather treats a symptom of that crowding. By vaccinating, managers address the current economic needs of stakeholders, but do not address the potential for change in the long term.

The intense political debates over proper elk and brucellosis management revolve around efforts to meet the current needs of the varied stakeholder groups and do not address the potential for ecological change. The economy is optimized for the today's

ecological conditions, and changes from the current conditions will require an economic reorganization. For example, if something happens to the elk population, both the hunting and tourism industries will be affected. Optimizing the system for elk population size undermines the resilience of the both the ecosystem and the local economy.

Leaving discussion of wolves out of conversations about the wildlife feeding program is similarly myopic. Wolves, were they to reestablish themselves in the area, could change the distribution of elk in the region. The elk that currently form a dense herd near Jackson might disperse over a greater geographic area or congregate in a less conspicuous area, potentially affecting the local economy as well. From the local stakeholders' standpoint, wolf population dynamics are largely uncontrollable. Wolf reintroduction policies, though informed by local interests, are also a national issue with nationwide stakeholder groups. Regional and state wolf management plans must fit within federal law, limiting the power of the states to manage the packs. Wolves can be seen as a potential driver of change over which local interests have limited influence.

Brucellosis serves as a reminder that we are not always able to control our ecosystems through well researched and well intentioned management. Though ranching techniques have helped to provide some stability in the elk population and the economy that is dependent thereon, numerous uncontrollable and uncertain factors both within and outside of the system could disturb the apparent current stability of the system. This thesis is an investigation of the National Elk Refuge/ Jackson Wyoming social-ecological system and factors that could potentially drive changes from the current state. I use a scenario planning method to identify several storylines that highlight uncertainties and the potential for surprise within the system.

Scenario planning has been used for several decades for both military and commercial planning, and there is a growing precedent to use scenarios to assist in making ecosystem management decisions (Peterson et al. 2003a). The technique is especially popular in settings with significant unknown variables. Peterson et al. (2003a) argue that scenario planning is a powerful tool for ecosystem management because traditional planning methods are unable to account for the uncertainty and nonlinear dynamics

exhibited by social-ecological systems. Scenarios are not intended to be forecasts of future conditions, but are built in situations wherein accurate forecasts are not possible.

“Scenarios are constructed to provide insight into drivers of change, reveal the implications of current trajectories, and illuminate options for action” (Peterson et al. 2003a). The storylines help decision makers deal with uncertainty because they provide a framework from which to begin a discussion of ecological dynamics, the implications of our choices, and potential futures (Peterson et al. 2003b). The technique works because it encourages decision makers to focus on the interconnections and uncertainties inherent within any system.

Because the Jackson economy depends so heavily on the local ecosystem, an outbreak of chronic wasting disease amongst elk could have significant social impacts and would likely result in a fundamental reorganization of the social-ecological system. Tourism and hunting based sectors of the economy would suffer and destabilize other local industries. An ecosystem reorganization driven by wolf reestablishment could similarly cause a reorganization of the local economy. Scenario planning is a technique by which managers and stakeholders can expand their views and plan for uncertainties. By creating a range of potential future scenarios I hope to help these diverse stakeholders and decision makers reach consensus on long term management objectives and account for uncertainties in the system.

CHAPTER II

LITERATURE REVIEW

Using Science to Make Sound Management Decisions

While ecology has many methods for understanding the future, including prediction, forecasting, and projection... these are insufficient for ecological decision making because of the complexity of most ecological systems and our imperfect knowledge about how they work (Bennett et al. 2003).

Because we live in a dynamic world, policies that are based on conditions experienced in the past are likely to be ill suited to address future conditions. Policy makers therefore seek to make decisions based on conditions that they are likely to face in the future. As Peterson et al. (2003b) explain, ecosystem managers depend on ecological knowledge and prediction to make wise policy decisions.

Management depends on choosing the best approach from a set of alternatives. Evaluating alternatives depends on understanding the future consequences of current actions. That is, managing ecosystems and ecological services depends on ecological prediction.

Failure to anticipate future threats and changes can have large economic and social costs. Enacting a change without definitive evidence that future conditions require the change is often controversial as well because of actual or perceived costs. Because there is significant motivation for decision makers to act despite incomplete knowledge as well as a cost associated with change that may or may not be necessary, ecosystem management decisions are typically rife with controversy.

Scientific prediction is alluring to policy makers because it lends an air of authority to contentious decisions. Sarewitz and Pielke (2000, p.17) describe this role for predictive science:

If predictive science can improve policy outcomes by guiding policy choices, then it can as well reduce the need for divisive debate and contentious decision

making based on subjective values and interests. Prediction, that is, can become a substitute for political and moral discourse. By offering to improve policy outcomes, scientific predictions also offer to reduce political risk, and for policy makers worried about public support and reelection, avoiding political risk is very appealing indeed.

Seeking both to make wise decisions as well as to avoid contentious debate, policy makers turn to scientists for predictions of future conditions upon which to base their policies. Though science can and should inform policy decisions, policies based exclusively on ecological modeling are problematic on several different levels: 1) ecosystems are complex and defy reductionist science and prediction (Sarewitz and Pielke 2000: , Bennett et al. 2003); 2) predictions are profoundly influenced by factors that are included and those ignored in the models; and 3) scientists, policy makers, and the public interpret uncertainty differently, creating communication and interpretation errors between those groups (Kinzig et al. 2003). Each of these failings will be described more thoroughly below.

Ecology and Prediction

Predicting the future of the Yellowstone ecosystem is professionally hazardous—some would say foolhardy. (Smith et al. 2003)

Modern society often calls on scientists to make predictions ranging from weather forecasts to epidemiological models of flu pandemics. These demands on science represent a relatively new view of science's capabilities (Oreskes 2000). Prediction in science originated with the reductionism tradition of physics and chemistry (Sarewitz and Pielke 2000). Scientists in these disciplines traditionally performed most of their research in laboratories in which conditions were tightly controlled. When a researcher runs repeated trials of an experiment under controlled conditions, he or she can expect a similar result each time. The researcher is able to make a logical prediction of the outcome of subsequent trials. In reductionist science, knowledge is gained by changing individual variables. Changing one variable might lead to a new result, and repeated trials that have

the same outcome under the new conditions lend credence to the hypothesis that the altered variable was the cause of the altered result.

Distinct from the logical predictions of reductionist science are temporal predictions (Oreskes 2000). Whereas a logical prediction might be to say that earthquakes will likely continue to occur along the San Andreas Fault system in California based on patterns seen in the past, a temporal prediction would be to identify the date of the next earthquake. Both types of predictions can be useful to planners, albeit in different ways. Recognizing that earthquakes are likely to continue to occur along a fault, decision makers can help to minimize damage by requiring that buildings be built with earthquake-resistant technologies (Oreskes 2000). Knowing a specific date for when the next earthquake will occur is not necessary for society to take measures to increase the ability of structures to endure earthquakes. A National Weather Service hurricane warning is a temporal prediction. Managers are able to take advantage of a temporal prediction like a hurricane warning by arranging an evacuation for just the dates when the storm is expected to strike, thereby minimizing the social costs accrued by shutting a region down while maximizing protection of human life.

Though the advent of computer modeling has led scientists in many fields to attempt more types of predictions, physics, astronomy, and chemistry were able to make logical predictions early in their histories because they dealt with recurring events, such as repeated experiments in a laboratory. "For them, the future *was* accessible, because the events of interest would occur again—today, tomorrow, next week, next year"(Oreskes 2000: 29).

Biology (specifically ecology) and geology are fundamentally different because they are rooted in a tradition of observation and induction rather than the reductionism of physics, chemistry, and astronomy. Oreskes (2000) argues that the integrative earth sciences, namely ecology and geology, are ill suited to prediction because their techniques are based on observation of in-tact processes rather than reductionism. Ecologists are not able to take most ecological processes into the laboratory for repeated and methodically

varied experiments as do chemists and physicists. Sarewitz and Pielke (2000: 13) argue that the integrative earth sciences, including ecology and geology,

... have sought to understand nature 'as it is,' rather than as reduced to its component parts. That is, while traditional physical science isolates phenomena from their context in nature in order to understand the invariant characteristics of the phenomena, the integrative earth sciences study the context itself.

Kinzig et al. (2003) suggest that scientists have avoided addressing some important questions because they cannot be investigated in the laboratory. Questions involving entire ecosystems and landscapes, they argue, receive insufficient attention because their inherent complexity eludes reductionist approaches.

Scientists who do investigate in-tact ecosystems and landscapes face important limitations due to their inability to take their experiments into a controlled laboratory. Dealing with intact processes, ecologists do not benefit from the feedback of repeated trials to refine their models. Stewart (2000: 53) describes the consequences of this limitation:

In cases where feedback is limited or nonexistent, scientists may be reluctant to make predictions, but they will be pressured to do so because policy decisions cannot wait, and policy makers need judgments of informed experts. In such cases, scientists must rely on 'coherence' to make their judgments (Hammond 1996). In other words, the best they can do is make logically coherent judgments that are consistent with what is known about physical and biological processes.

Without the ability to reduce uncertainty, scientists' predictions are more heavily based on professional opinion, are likely to vary, and can at times contradict opinions of other respected scientists (Stewart 2000).

Ecosystem dynamics further complicate efforts to make accurate ecological predictions. Ecosystems respond both to changes in external conditions as well as to fluctuating internal dynamics (Scheffer et al. 2001). Though change can occur gradually, ecosystem conditions can also undergo abrupt and unexpected shifts (shown graphically in *Figure 2 Ecosystem dynamics*). This happens when the ecosystem reaches a threshold, and feedback loops that pushed the system toward the former state cease functioning. New feedbacks push the system toward a new state (Scheffer et al. 2001). Examples of these state-shifts include: 1) coral dominated ecosystems becoming algal dominated, and 2) grasslands shifting to shrub-bushland (Elmqvist et al. 2003). Scheffer et al (2001) warn

that “Indeed, such catastrophic shifts occur typically quite unannounced, and ‘early-warning signals’ of approaching catastrophic change are difficult to obtain” (591). The authors also state that elucidating the causes of these sudden shifts can be quite difficult because the phenomena influencing the system occur on varied spatial and temporal scales. The individual factors precipitating change may not be known and thresholds are difficult if not impossible to predict.

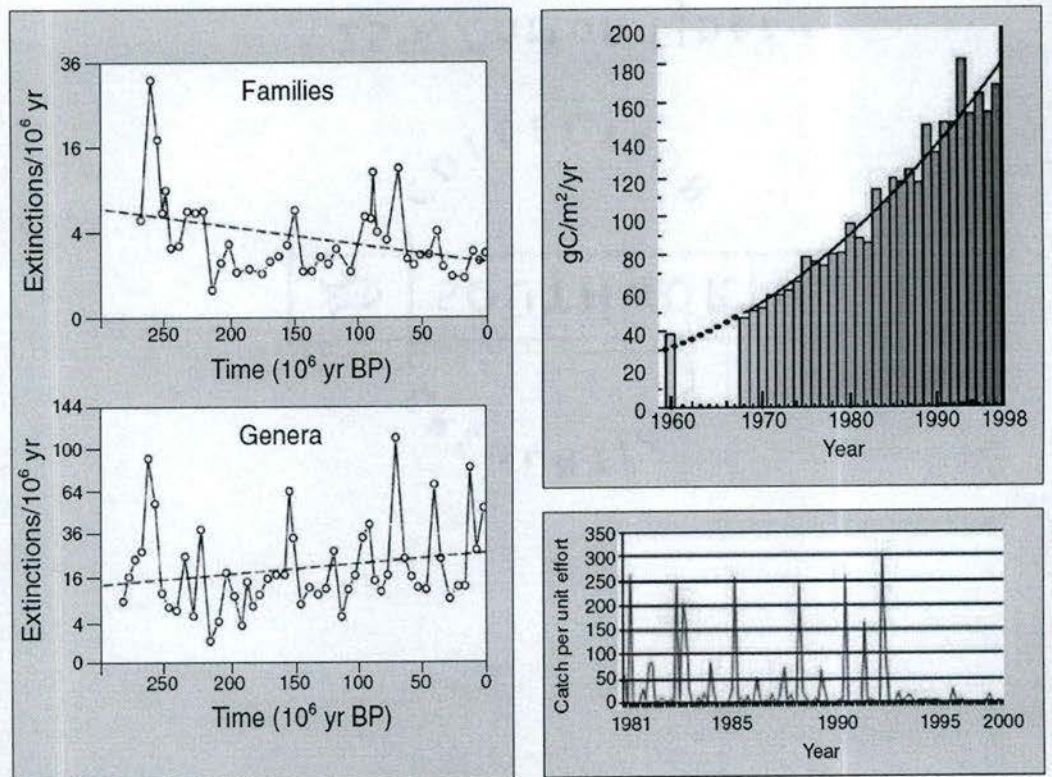


Figure 1. Long-term datasets showing non-stationarity, including trends, thresholds, and nonlinearities. (left) Extinction rates (taxa extinct per million years) since the mid-Permian. Reproduced from Quinn and Signor (1989), based on data from Raup and Sepkoski (1984); (top right) Annual primary productivity in Lake Tahoe, California/Nevada, between 1959 and 1997, reproduced from Goldman (2000); (bottom right) Catch per unit effort of yellow perch (*Perca flavescens*) in Crystal Lake, Wisconsin.

Figure 2 Ecosystem dynamics

Source: Bennett et al. (2002)

Computer models of ecosystem fluctuations first provided evidence of their tendency to suddenly shift between basins of attraction (Scheffer et al. 2001). This does not suggest, however, that models (mental or computer) are able to provide managers with

definitive predictions of when these shifts will occur. Ecosystem managers are likely to underestimate the importance of these sudden shifts when estimating potential future conditions simply because the thresholds at which the shifts occur are unknown (e.g., Langston 1995).

Bennett *et al.* (2003) offer a simple yet insightful critique of attempts to predict ecological dynamics: "If prediction worked well, experts would tend to come to consensus as more data became available, and the consensus would converge on the truth"(326). Experts rarely agree on a single prediction for the future of a complex system. Because ecosystem dynamics cannot be accurately deduced by dissecting the systems into their constituent parts, scientists have a difficult time identifying the thresholds that make ecosystem function unpredictable. Surprises remain important in ecosystem dynamics and a significant barrier to accurate long-term prediction.

Ecosystems are complex and defy accurate prediction. Traditional experimental reductionism does not work well in ecosystems because each system is unique and the social and environmental costs of experimentation preclude such efforts. Additionally, ecosystems are widely recognized to be greater than the sum of their parts; investigating individual components of an ecosystem does not elucidate the function of the whole. Ecosystems' sheer complexity limits our understanding.

Uncertainty in Ecological Predictions

Stewart (2000) suggests that due to ecosystem complexity, models thereof, whether mental or mathematical, necessarily exclude some factors that may be crucial to an accurate representation of their function. Outcomes of incomplete models can vary widely, often feeding the contention over management decisions (Stewart 2000).

When considering ecosystems on which people depend, scientists often neglect to consider humans to be a part of those systems. Despite the fact that humans have always influenced and been influenced by the ecosystems of which we are a part, western culture largely sees itself as living outside of the natural world (Cronon 1996). Contrary to this

dominant perspective, human history has been significantly influenced by the ecosystems in which we live, and people have long helped to shape the world around them (Robbins 1997). Ecosystem modelers, however, often ignore social dynamics in their models because, as Holling *et al.* argue, scientists avoid addressing social issues in an effort to maintain objectivity.

Scientific disciplines are often cocooned; scientific purity is assured by the assiduous avoidance of societal issues. For example, many scientific articles in ecology journals are based on field experiments in which human influence is thought not to exist. (1998: 345)

Humans, much like other influences on ecosystem dynamics, are difficult to accurately model. Humans behave reflexively, meaning that we change the way in which we interact with the world in response to both social and ecological changes (Clark *et al.* 2001, Walker *et al.* 2002).

Social and ecological systems are the subjects of different disciplines, each with its own sets of theories, models, and explanations. Natural resource management issues are a nexus of these two disparate academic disciplines (Westley *et al.* 2002). Ecological studies tend not to address social issues because of the traditional disciplinary divide between the two fields.

Much ecological theory, for instance, has been developed in systems that are absent humans, or in systems where humans are considered an exogenous, simple, and detrimental perturbing force. The intricate ways in which humans might interact with ecological systems—both visiting and responding to ecological change—are rarely considered. (Kinzig 2001: 710)

That ecologists tend to avoid systems in which humans have an obvious influence is problematic because it limits the usefulness of ecological studies in making resource management decisions.

Misunderstanding Between Scientists, Policy Makers

As shown above, the certainty of ecological models and predictions is limited by a number of factors. Due to ecosystem complexity, uncertainty is inherent in any ecological prediction. Planners and scientists have different incentive structures affecting the way

practitioners of the two fields deal with uncertainty, leading to a number of problems related to how science is utilized in the decision making process.

First, producers of science and those who hope to use it to make wise decisions have different incentive structures and evidentiary standards. The scientific method mandates that scientists refrain from publishing results until hypotheses have been repeatedly tested. They seek to avoid making false claims because the scientific process builds on past hypotheses and experiments; an error now could have significant costs if future work is built on a false premise (Lee 1993). Kinzig et al. (2003) describe scientists' reluctance to act in the face of uncertainty:

Scientists apply relatively high evidentiary standards—insisting, for instance, that there be only a small probability (sometimes 5% but frequently lower than 1%) that an incorrect conclusion has been drawn. This means that many conclusions concerning the workings of the world that have a reasonable probability of being correct—say 75%—may not pass muster. (p.330)

Decision makers have other incentives that contribute to their management decisions and the way they make decisions in the face of remaining uncertainty. Policymakers do not always have the liberty of waiting for scientific certainty and consensus because of social or environmental costs associated with inaction (Lee 1993, Kinzig et al. 2003). For example, ecosystem managers may want to intervene when a species is going toward extinction, but scientists might be reluctant to say that the species is likely to go extinct because of lingering uncertainty. Science cannot *prove* that a species is going to go extinct until the last member of the species dies, and saving a declining species requires action prior to scientific proof. The information planners need is not always available at the time when it would be of most use to them. Because scientists apply different evidentiary standards than do decision makers, the users of scientific knowledge do not always have access to information they need.

A second potential misunderstanding between scientists and policy makers stems from the nature of ecological predictions. Scientists may have trouble quantifying uncertainty in predictive models because of the sheer complexity and incomplete understanding of ecosystem dynamics. In such situations, measuring uncertainty in

prediction becomes a subjective enterprise (Kinzig et al. 2003). Scientists may or may not make explicit the uncertainty inherent in their models.

Peterson et al. (2003a) argue that ecological predictions are rife with uncertainty, and that authors of those predictions seldom evaluate that uncertainty. Uncertainty is significant enough that:

When the uncertainty of forecasts is rigorously evaluated it is usually found that it assigns roughly equal probability to an enormous range of extremely different outcomes. (p.359)

Problematically, policy makers and society in general often do not necessarily understand the uncertainty inherent in any ecological prediction. Oreskes (2000) suggests: "In many cases, these temporal predictions are treated with the same respect that the hypothetico-deductive model of science accords to logical predictions" (p.35). This trust is misplaced, the author continues, because:

...the bigger the prediction—the more ambitious it is in time, space, or complexity of the system involved—the more opportunities there are for it to be wrong. If there is a general claim to be made here, it may be this: the more important the prediction, the more likely it is to be wrong. (2000: 36)

When uncertainty is not made explicit, scientific models are often viewed by the public and decision makers as definitive truths.

With so much uncertainty built into the modeling and prediction processes, ecological predictions and their interpretation can cause misunderstanding and actually increase political conflict. Predictive information is not conclusive, and is therefore prone to misunderstanding. Sarewitz and Pielke (2000: 19) argue that:

Predictive information may be subject to manipulation and misuse, because the limitations and uncertainties associated with predictive models are often not readily apparent to nonexperts, and because the models are often applied in a climate of political controversy and/or high economic stakes.

Natural resource management decisions are often controversial, and people arguing on either side of a given issue will take full advantage of a model that appears to validate their position. Scientists may understand that their predictions are uncertain and include numerous assumptions, but the public holds complex predictions to be truths. Advocates of

a position that appears to be supported by a prediction have additional incentive to portray that prediction as being far more certain than it may in fact be.

Another potential problem with communication of ecological prediction between scientists and the users of the science is that politicians and policy makers may be tempted to delay action in the face of contradicting scientific opinions of future conditions, potentially with great expense to both society and the ecosystem. It is crucial that decision makers and the public recognize scientific uncertainty. Kinzig et al. (2003) propose that ecosystem management decision making processes are fundamentally subjective processes. "... [W]e cannot avoid making a subjective judgment concerning the likelihood of surprise and using it to compare the risks against lost benefit" (p. 332). Value discussions, the authors suggest, are not in the realm of science and should be left to the public.

Management Mistakes

Despite the uncertainty inherent in ecosystem management enterprises and our incomplete knowledge of ecosystem dynamics, managers have attempted to manage and control ecosystems. Believing ecosystems to be essentially machines constructed of a multitude of independent parts, managers have long tried to simplify and control ecosystems to optimize production of desired goods and services (Robbins 1997, Scott 1998). There are many examples of ecosystems which managers thought they understood and could control through simplification and control, including forests (Langston 1995, Scott 1998), fisheries (Lichatowich 1999), and national parks (Sellars 1997).

Holling et al. (1998: 353) clarify that ecosystem complexity causes many management regimes to fail:

The inherent unpredictability of ecosystems plays havoc with conventional resource management science, which starts with the assumption of a clockwork, predictable world in which sustained yields can be predicted, given enough information.

Even modern concepts of “sustained yield,” which pay lip service to long-term sustainability, are predicated on a mechanistic worldview. As Holling et al (1998: 347) argue,

The concept of sustained yield developed in the service of a utilitarian worldview in which nature was seen as a storehouse of raw materials, and resources as merely commodities, and humans had 'dominion over nature'. The mathematical treatment of the supply and demand of these resources/commodities employed a reductionist approach, and essentially ignored the fact that these 'products' were embedded in ecosystems.

Ecosystem managers have traditionally tried to improve upon nature's efficiency by simplifying the system and doing away with waste, believing ecosystems to be machines which could be tuned and optimized. Ecosystem complexity, however, precludes success of these reductionist attempts at resource management. Though often effective in increasing ecosystem output in the short run, many attempts at ecosystem simplification and control are unsustainable and lead to unforeseen and often undesirable results (Langston 1995: , Scott 1998).

Examples of naïve but well intentioned management pervade modern history of the American West. Despite their good intentions, forest managers inadvertently changed the Blue Mountains in Oregon and Washington from a Ponderosa Pine dominated system to a disease and fire prone system dominated by firs (Langston 1995). In the course of explaining the reasons for managers' inability to control the forest, Langston argues that “attempts to control natural systems were often self-defeating: they introduced an element of instability into the systems they were supposed to be stabilizing” (296). James Scott, in his book Seeing Like a State (1998), uses the term ‘high modernism’ to describe the approach managers used to administer forests for the past century. High modernism is defined among other things by an over-riding faith in technological progress and our ability to control nature. Control over nature necessitated categorizing it so that centralized planners could make management decisions for otherwise varied landscapes. Effective central management required forest uniformity – natural variation had to be minimized. Control over nature is predicated on a worldview in which ecosystems are seen as machines, and managers assumed that they could do away with uncertainty by controlling

system dynamics. Management failures like the one Langston describes elucidate the fact that natural systems vary in ways that are not always predictable or controllable.

Managing with Uncertainty

Adaptive Management

Heavy-handed management based on a mechanistic world view has caused systems to react in ways managers did not predict (Scott 1998). In recent years, new management strategies have emerged to address some of the shortcomings described above. Proponents of adaptive management recognize that ecosystems can not be adequately explained by reducing them to their constituent parts. Advocates of adaptive management propose that managers use management decisions as large-scale experiments because our current knowledge is insufficient to manage ecosystems (Lee 1999). Under adaptive management, management policies become experiments of ecosystem response to anthropogenic forces. When there are multiple similar systems that must be managed, proponents of adaptive management advocate using different approaches for each system to help determine the optimal management regime (Bormann et al. 1999). All of the management regimes should have a reasonable chance of being successful (Bormann et al. 1999). As the management experiment proceeds, techniques are adjusted to include knowledge gained through previous efforts. This approach acknowledges that humans are dependent on the ecosystems we inhabit and exercise significant influence on their dynamics. Adaptive management is most successful when locals who have knowledge of ecosystem workings based on long-term experience and observation are included in the management process. As such, adaptive management includes stakeholders in management processes as a source of knowledge and experience and as ecosystem monitors (Lee 1993, Bormann et al. 1999)

Kai N. Lee (1999) appraises the success of adaptive management as applied to real world situations. He found that significant problems remain with the way adaptive management has been applied, but that the social learning that is inherent within the

adaptive management process is crucial if society is to learn to live in a sustainable manner. Breaking through entrenched positions is not guaranteed as part of the adaptive management approach, however. Unless there is consensus amongst stakeholders early on as to the goals of management, Lee concludes that “adaptive management is no more than a way to justify trial and error in the midst of a political free-for-all” (Lee 1999). Part of the value of the approach for managers and policy makers is that adaptive management allows action when it is socially necessary, even while uncertainty remains. This flexibility is critical in management situations in which there are large social or environmental costs associated with delayed action.

Though it is a valuable approach because it allows action despite lingering uncertainty, the ecological costs of adaptive management can be high if the ‘experiment’ causes a decline in valued biota. In situations in which there is a large amount of uncertainty about the likely outcome of a management experiment, Peterson et al. (2003a) recommend that a scenario planning approach be integrated into adaptive management to ensure that the plans enacted are robust to a variety of future possibilities. Scenario planning is the optimal approach when there is a great deal of uncertainty and that uncertainty is not controllable (Peterson et al. 2003a; see Figure 3 Optimal planning strategies). The scenario planning approach will be explained in detail beginning on page 25.

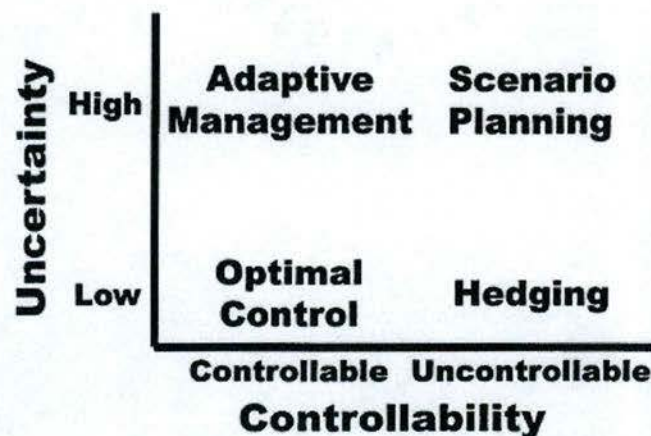


Figure 3 Optimal planning strategies

Scenario planning is appropriate for systems in which there is a lot of uncertainty that is not controllable. In other cases optimal control, hedging, or adaptive management may be appropriate responses

Source: Peterson et al. (2004)

Ecological Resilience and Management

"Nature is not fragile ... what is fragile are the ecosystem services on which humans depend" (Levin 1999).

A considerable body of literature on resilience of ecological and social systems has accumulated in the past 30 years. Walker et al. (2004) define resilience as:

... the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks—in other words, stay in the same basin of attraction.

Authors have expanded the scope of resilience theory to include what they call social-ecological systems (SESS; systems in which social interests affect ecosystems and vice versa) in recognition of the fact that society and our ecosystems are intertwined. We depend on ecosystem goods and services, and humans exercise agency over the condition and state of our ecosystems. As explained by Holling and Gunderson (2002: 25-27), social-ecological systems experience episodic change. Ecosystem dynamics are influenced by factors operating on a wide variety of spatial and temporal scales (a phenomenon the

authors term Panarchy). The complex interactions of these factors lead to sudden, often unexpected, and drastic changes in ecosystem state. Proponents of the ecosystem resilience theory believe that ecosystems do not have a single equilibrium towards which they tend, but rather “multiple equilibria commonly define functionally different states” (Holling and Gunderson 2002: 26). When pictured graphically, the “nature is resilient” stability landscape is represented by basins of attraction of various sizes (see *Figure 4 Descriptions of four myths of nature*). Holling and Gunderson (2002) propose that due to the variability inherent within SESs, application of fixed management rules to achieve sustained yield of a good or service reduces the system’s resilience. Systems under fixed management regimes lose the ability to absorb disturbances that would not have affected the system otherwise, making the system more likely to shift to a different basin of attraction.

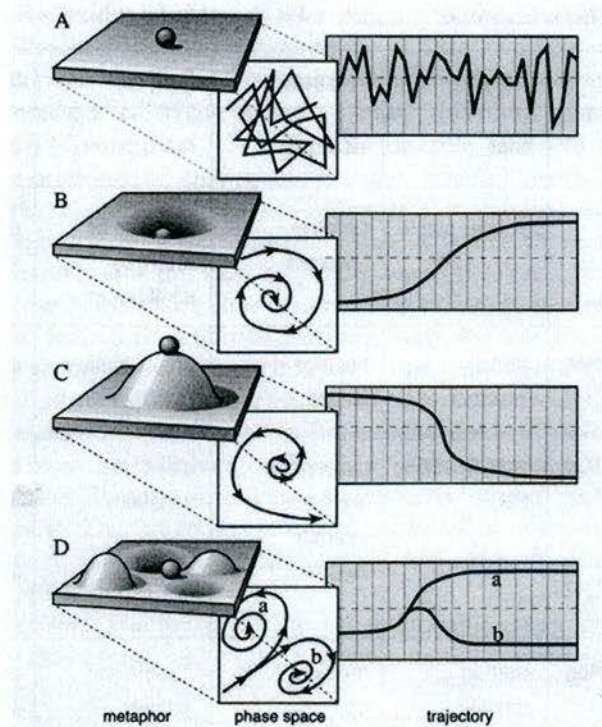


Figure 4 Descriptions of four myths of nature

Depictions of four myths of nature: (A) Nature Flat, (B) Nature Balanced, (C) Nature Anarchic, and (D) Nature Resilient. Each myth has three representations or metaphors: as stability landscape (left), phase diagram (center), and time-course chart or trajectory of key system variables over time (right).

Source: Holling et al. (2003b)

Walker et al. argue that because of the extensive uncertainty involved in ecosystem management, "... we must focus on learning to live within systems, rather than control them" (Walker et al. 2002). They believe social-ecological systems move through cycles consisting of four steps: 1) growth and exploitation; 2) a stable period of accumulation and monopolization (reduces system resilience); 3) rapid breakdown; and 4) reorganization and renewal.¹ This progression is represented graphically in *Figure 5 Resilience and multiple states*. When society becomes dependent on ecosystem products, it tends to manage for optimal production of those goods and services (step 2). Optimizing for a single species or

¹ The summary presented here is a close paraphrase of the adaptive cycle as presented by Walker et al. (2002). Walker et al build from the adaptive cycle analogy proposed by Holling (1986).

process tends to simplify ecosystems, thereby undermining resilience. The ecosystem reaches a threshold (step three), forcing it into an undesirable state—a different basin of attraction (step four). The social structures then must adjust to the new ecosystem conditions. State changes in social-ecological systems may be irreversible if key components or dynamics of the system are lost or fundamentally altered through ecosystem simplification. In this mental model, society and ecology, connected through management and human dependence on ecological goods and services, are part of the same social-ecological system. (Walker et al. 2002)

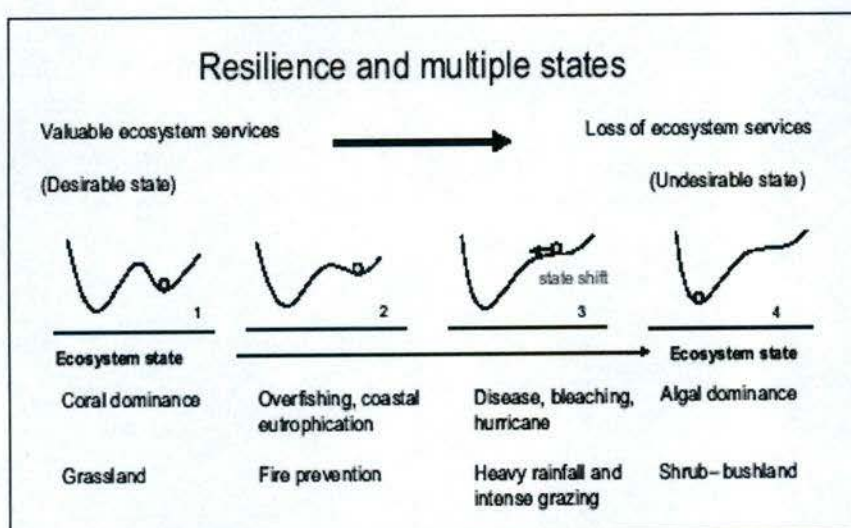


Figure 5 Resilience and multiple states. Shifts in ecosystems from a state of high human-utility to states of lower utility. The shapes of the basins gradually change from left to right as system resilience decreases. The management regime presented in diagram 2 undermines system resilience, thereby making it more susceptible to perturbation. As the ecosystem shifts between states, social systems adapted to the desirable state (1) must reorganize and adapt to the conditions present in the undesirable state (4). Adapted from Elmqvist et al. (2003)

Resilience management focuses on creating management strategies that are robust to a wide variety of future conditions and unexpected changes. In the ball and cup metaphor, increasing resilience means increasing the diameter of the cup, making it less likely that the system will shift to an undesirable state. Elmqvist et al (2003) suggest that preserving the availability of ecosystem functional groups, or groups of species that perform similar roles on comparable spatial and temporal scales, is critical to maintaining

resilience. When functional groups are lost as part of ecosystem simplification and 'optimization,' the system becomes vulnerable to disturbance that the system was formerly able to absorb. The size of the cup decreases, meaning that smaller disturbances are capable of pushing the system to a new state.

Ecosystem optimization, the goal of much ecosystem management throughout the past century (Scott 1998), is incompatible with ecosystem resilience optimization. As Walker et al. (2002) describe the approach, resilience management requires managers to abandon their attempts to optimize ecosystems for production of desired goods and services:

Cast in the language of optimal control, there is no attempt to keep the system on some predicted, optimal path. Rather, the policies are aimed at a set of rules (incentives and disincentives) that enhance the system's ability to reorganize and move within some configuration of acceptable states, without knowing or caring which particular path the system might follow. [...] There are many particular states (combinations of state variables) that will provide the desired supply of ecosystem services. *Thus, the important thing is not to try to maximize the supply by aiming for a particular state, but rather to remain within the system configuration into which these desirable (acceptable) states fall.* (emphasis added)

They argue that accepting lower production of ecosystem services is worthwhile because living within the systems limits reduces the chances of substantial changes to the system. Social systems are far better suited to accommodate small changes in ecosystem production of goods and services than they are to deal with potentially irreversible collapse of the system.

In social-ecological systems wherein stakeholders are dependent on ecosystem goods and services, achieving the resilience management ideal of allowing the system to fluctuate rather than managing to optimize production requires buy-in and thorough understanding from all stakeholders (Walker et al. 2002). A system optimized for resilience is not optimized for production of goods and services. If all stakeholders are not on board with the management regime, some are sure to object to what they might term negligent management because our society is accustomed to managing for optimal output. To encourage stakeholder buy-in, Walker et al. (2002) recommend a scenario planning

process building from stakeholder input. Scenario planning is a powerful tool for bringing the public into the planning process, increasing planning transparency and tapping into local ecological knowledge.

Scenario Analysis

Scenario analysis is the process of identifying factors that could drive change in a system, then systematically and creatively varying them in storylines about the future development of that system (Fahey and Randall 1998a: , Peterson et al. 2003a). "The central idea of scenario planning is to consider a variety of possible futures that include many of the important uncertainties in the system rather than to focus on the accurate prediction of a single outcome" (Peterson et al. 2003a: 359). The technique was originally developed as a military planning tool and has a long history of application in industry (van der Heijden 1996). It was recently adapted for use in the United Nations Millennium Ecosystem Assessment (Reid et al. 2002) and has been embraced by the Environmental Protection Agency as a tool to anticipate future challenges (Beyond the Horizon: Using Foresight To Protect the Environmental Future 1995). The technique has been used in several regional-scale social-ecological system planning processes (Wollenberg et al. 2000: , Peterson et al. 2003a).

Hermann Kahn, one of the early practitioners of the scenario planning technique, worked at the RAND corporation and used scenarios to aid in planning for contingencies for the military (Ringland 1998). Later Kahn became well known for his idea that he could help prevent nuclear war by thinking through what might result, and publicizing those scenarios (Ringland 1998). His approach was to envision potential futures by separating factors that influence a particular system into those that are predictable and those that are not. He produced varied scenarios by holding the predictable variables constant in each, and varying those that are not predictable (van der Heijden 1996).

Scenario analysis was quickly adopted by other industries for use as a planning tool. Shell Oil was one of the first organizations to favor using scenarios that did not assign probabilities to the various futures, but instead focused on examining the range of what is

possible (van der Heijden 1996). Shell evaluates potential projects in light of several potential futures to evaluate the wisdom of completing the project given the range of possible events (van der Heijden 1996). In a scenario planning exercise, planners at Shell constructed a scenario in which countries that controlled oil production limited access to their reserves, resulting in an unexpected decrease in oil supply. This storyline was only one of several that they created, but when the oil crisis began to unfold in the early 1970s, Shell managers recognized that their "crisis" scenario might actually represent the future. Because they had considered their crisis scenario as a possibility, the company was quick to recognize the events for what they were. Shell Oil was able to make strategic changes that helped them outperform their competitors which assumed that supply would follow a predictable trend (van der Heijden 1996). Van der Heijden explains that:

What the scenarios did was to enable Shell's manufacturing people to be more perceptive, recognize events for what they were, a part of a pattern, and on this basis realize their implications. As a result of this, they were able to respond quickly to events in a way that would have been impossible without the mental preparation of the scenario analysis. (van der Heijden 1996: 19; bold in the original)

Scenario planning was valuable to Shell Oil not as a predictive tool, but rather because it made managers alert to possible future surprises, which helped them to recognize an unfolding crisis and react quickly.

Scenario planning processes are helpful even if none of the envisioned storylines turn out to represent the course of events as they play themselves out. "The point ... is not so much to have one scenario that "gets it right," as to have a set of scenarios that illuminate the major forces driving the system, their interrelationships and the critical uncertainties" (Wack 1985: 67). The scenario planning process is helpful because it introduces a wide range of possible futures and inspires discussion of system dynamics and uncertainty. Because scenarios do not depend on accurate prediction, they can be useful in situations in which great uncertainty remains. Wollenberg et al. explain that: "Scenarios help stakeholders cope with uncertainty, not by eliminating it, but rather by framing it and understanding the range of associated implications"(2000: 71). The benefits of scenario

analysis accrue whether or not one of the scenarios turns out to be an accurate representation of future events.

The storylines created in a scenario planning process are not assigned relative probabilities and are not meant to be forecasts. Scenario planning acknowledges that it is difficult to predict future conditions, and there can be costs associated with getting it wrong.

Most planners and futurists today would reject the idea that planning should be conducted against a single 'most likely' scenario or image of the future, since all futures will contain surprises and no particular future that we can describe is in the statistical sense very likely (Futures Methods and Issues: A technical annex to "Beyond the Horizon: Protecting the Future with Foresight" 1995: 7)

Scenarios embrace uncertainty as a key characteristic of any system. "Unlike forecasts, scenarios stress irreducible uncertainties that are not controllable by the people making the decisions" (Peterson et al. 2003a: 360). Scenario analysis represents a systematic way of addressing nonlinearities, surprises, and uncertainties – dynamics that are often ignored in traditional modeling and predictive techniques. By creating storylines that cover a range of possible trajectories, planners can use the scenario planning process to evaluate current policies in terms of how well they address potential future situations. Creating scenarios allows decision makers to choose plans robust to a number of potential futures and less sensitive to the uncertainty and variability that can be difficult to predict (Bennett et al. 2003).

Though the process was developed for military and industry planning, there is a growing precedent to use scenarios to assist in making ecosystem management decisions (Peterson et al. 2003a). Peterson et al. (2003) argue that scenario planning is a powerful tool for ecosystem management because traditional planning methods are unable to account for the uncertainty and nonlinear dynamics exhibited by social-ecological systems. Scenarios are not intended to be forecasts of future conditions, and are in fact most useful when accurate forecasts are not possible. In ecological management situations, scenarios help decision makers deal with uncertainty because they provide a framework from which to begin a discussion of ecological dynamics, the implications of our choices, and potential

futures (Peterson et al. 2003b). The technique works because it encourages decision makers to focus on the interconnections and uncertainties inherent within any system.

Ecosystem management decisions can be highly contested and controversial because stakeholders often have multiple competing claims on the same resources. Multiple authors have argued that scenario planning is a valuable tool in helping to break down some of the barriers to understanding the system in contested situations.

Scenarios introduce hypothetical possibilities that spur people's imagination and enable them to adjust their mental habits. They enable stakeholders to overcome cognitive biases to (1) undervalue that which is hard to remember or imagine, (2) better remember and give more weight to recent events, (3) underestimate uncertainties, (4) deny evidence that does not support one's views, (5) overestimate their ability to influence events beyond their control, (6) be overconfident about their own judgments and (7) overestimate the probability of desirable events. (Wollenberg et al. 2000: 67)

Peterson et al. argue that in controversial decision making processes, "...scenario planning allows people to step away from entrenched positions and identify positive futures that they can work at creating" (Peterson et al. 2003a: 362). Bonnett and Olson suggest that scenario analysis allows managers to "...break free of their conventional obsession with immediate and short-term problems" (Bonnett and Olson 1998: 308). Scenario planning is an invaluable tool for helping stakeholders and managers to break through their entrenched positions and focus on creating policies robust to a number of potential futures.

The United States Science Advisory Board, a Congressionally mandated group of scientists engineers and professionals, recently issued a report entitled "Beyond the Horizon: Using Foresight to Protect the Environmental Future (Beyond the Horizon: Using Foresight To Protect the Environmental Future 1995)" which advised that the Environmental Protection Agency embrace scenario planning as a way to resolve environmental problems. The report stated that the traditional approach of dealing with environmental problems after-the-fact is insufficient. "It is essential for EPA—and for other agencies and organizations whose activities affect the environment—to begin to *anticipate* future environmental problems, and then take steps to *avoid* them, not just *respond* to them after the fact" (Beyond the Horizon: Using Foresight To Protect the Environmental Future 1995: 1). The authors of the report emphasize that change is

inexorable, but that by anticipating that change through scenario planning, some of the costs associated with unexpected change can be avoided.

Environmental decision making is often contentious and involve a large number of stakeholders. Scenario planning is a powerful tool for bringing the public into the planning process because the storylines are in a format that is accessible and familiar to non-scientists (Wollenberg et al. 2000, Bennett et al. 2003). Stakeholders are able to use the scenarios as a basis for discussion about their views (Wollenberg et al. 2000), and this accessibility increases planning transparency for the public. Participants in the scenario creation process can contribute their knowledge and understanding of the social-ecological system to the conversation, providing a venue for local ecological knowledge to influence the planning process.

As argued previously, ecological predictions and forecasts often contain significant uncertainty, and the communication of that uncertainty to the users of the science can be problematic. By using a scenario analysis process to create policy, managers can avoid some of the potential pitfalls associated with communicating science and uncertainty between scientists and managers (Reid et al. 2002). The interpretation of uncertainty is not problematic because it is made explicit that scenarios do not represent forecasts or predictions; rather they are merely possibilities (van der Heijden 1996). Similarly beneficial, managers do not have to wait for scientific consensus before acting, avoiding potential economic and environmental costs of delaying action (Beyond the Horizon: Using Foresight To Protect the Environmental Future 1995).

Scenario analysis has long been used by the military and industry to aid in long-term planning. The technique is gaining favor in ecological management settings because it acknowledges our incomplete ecological knowledge and the dynamic nature of our world. The process changes the management conversation from what we definitively know about the future to what is possible.

Based on the established scenario planning methodologies in industry and lessons learned from adaptive management, Peterson et al. (2003a: 360-362) identify six steps to the scenario planning process for application in natural resource conservation:

1. **Identify the focal issue-** a specific question should be identified. Knowable aspects of the future should be separated from those about which uncertainty remains. Problems should be defined in a way that they represent the views of a broad range of stakeholders.
2. **Assessment-** this step involves assessing the workings of the social-ecological system, including the people, institutions, ecosystems, and linkages that define the system. Internal and external drivers of system dynamics are defined. Special consideration should be paid to those uncertainties that could potentially have a large impact on the focal issue.
3. **Identification of alternatives-** determine ways in which the system could evolve, taking into account what is known about system dynamics and the uncertainties that remain. "Scenario planning usually focuses on uncontrollable uncertainties because the attempts of stakeholders to address controllable problems should be included within a scenario's dynamics" (361).
4. **Building scenarios-** the alternatives generated during the previous step are crafted into storylines by adding narrative descriptions of external forces and peoples' responses. The progression of events should be plausible and logically coherent. To help make the scenarios accessible to potential users, each storyline should be given a title that "evokes its main features" (362).
5. **Testing scenarios-** the scenarios should be reexamined to verify that they are plausible and consistent with what is known about system dynamics and actor behaviors. Scenarios are then refined so that they are plausible.
6. **Policy screening-** current policies are screened to determine how well existing policies would fare in different scenarios. "Such an approach can identify weak policies and those that are more robust to uncertainty about the future" (362). When included in this step, people can learn to "... think more broadly about the future and the forces that are creating it and to

realize how their own actions can move the system toward a particular kind of future. In this way, scenario planning allows people to step away from the entrenched positions and identify positive futures that they can work at creating” (362).

The identification of a focal issue and system assessment steps can be further broken down. In order to identify a focal issue and identify key uncertainties, scenario authors must first describe the current state of the system and what is known about how it reached its current condition (van der Heijden 1996). The next step is to create a mental map that describes interconnections between system components based on how the system reacted in the past and what is known about system dynamics (Wollenberg et al. 2000, Peterson et al. 2003b). The structure of the system is mapped out, including the ecosystem, human demands on and uses of the ecosystem, local institutions, and the relationships between the above systems. Peterson et al. (2003b) create a flow diagram to facilitate the understanding of the relationships between the drivers, actors, and the ecology (see Figure 6 Human uses of ecosystem services).

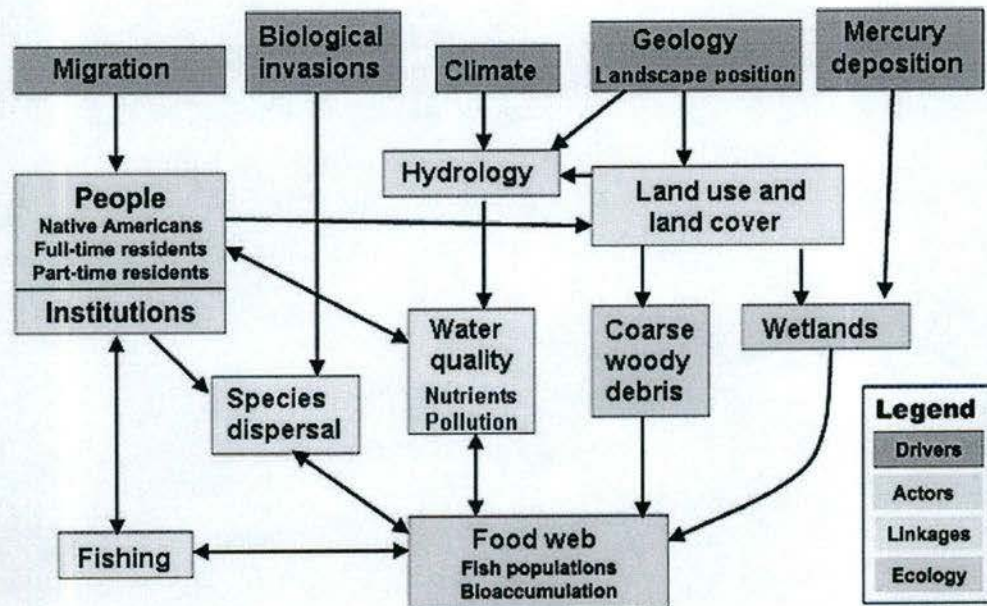


Figure 6 Human uses of ecosystem services in Wisconsin's Northern Highlands Lake District

The human use of ecosystem services in Wisconsin's Northern Highlands Lake District depends on the connections among the actors, linkages, ecosystem properties, and drivers within the region. Although people and nature are connected in a diversity of ways, the strongest connections are illustrated in this figure.

Source: Peterson et al. (2003b)

Oglivy and Schwartz (2004: 3) emphasize that identifying a pertinent focal issue is a critical step in the scenario analysis process. To be useful to planners and stakeholders, the scenarios must address the needs of stakeholders and decision makers. "Stakeholders may even help identify the risks, goals or policies that define the scenario themes" (Wollenberg et al. 2000: 69). Scenarios should highlight the potential influence that surprises could have on system dynamics (Wollenberg et al. 2000, Peterson et al. 2003a, Oglivy and Schwartz 2004). "Useful scenarios incorporate imaginative speculation and a wide range of possibilities; those based only on what we currently know about the system have limited power because they do not help scenario users plan for the unpredictable" (Peterson et al. 2003a: 360). The power of the scenario analysis process over other planning techniques is that it provides a way of addressing significant uncertainty in ecological and social forecasts and predictions; focusing on those uncertainties in scenario analysis exercises provides a systematic way of dealing with uncertainty.

The scenarios should all share a date that serves as the end-point of the storylines. Scenarios are most valuable, however, when the storylines on the progression of events from current conditions rather than on the end point conditions (Fahey and Randall 1998b).

Possible values for key uncertainties can be integrated into the storylines following either an inductive or a deductive method (van der Heijden 1996, Schwartz and Oglivvy 1998). Inductive scenario development involves building storylines by combining possible future events and connecting them with a logical narrative progression. Scenarios are constructed by adding events from current time and the horizon-line conditions are not known at the beginning of the storyline construction phase. The inductive method is fairly unstructured and relies heavily on the creativity of the scenario authors.

The deductive method is more structured and begins with prioritization of the key uncertainties. In situations where stakeholders are involved in defining the key question and uncertainties, some authors recommend allotting each participant a set number of poker chips (Wollenberg et al. 2000). Once the group has brainstormed a thorough list of uncertainties, each participant ranks the relative importance of the uncertainties by allocating their poker chips to the uncertainties they view as most important or furthest upstream (i.e., those that influence the most other uncertainties). The two uncertainties deemed to be are placed in a scenario matrix (Peterson et al. 2003b). See *Figure 7 Scenarios in relationship to key drivers* for a graphical representation of a 2x2 scenario matrix. The end-state of each scenario is represented by the location of the circle representing that scenario on the matrix. For example, in scenario 2 (Figure 7), both of the uncertainties are quite important in determining the conditions at the horizon-line for the scenario exercise. In Figure 3, however, uncertainty axis A is minimally important and uncertainty axis B is quite important. The scenarios are built around end-states, as described by each storyline's position on the matrix. Details and events are filled in to make a logical progression from the current system to the one described by the matrix.

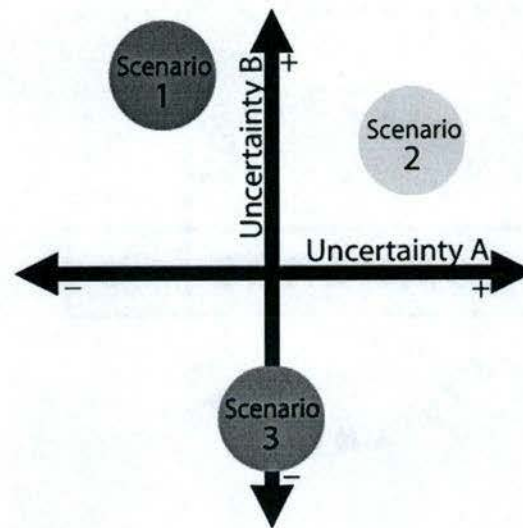


Figure 7 Scenarios in relationship to key drivers

There are two key uncertainties in this generic scenario matrix. The end point, or “horizon-line” conditions are defined primarily by the two uncertainties represented on the matrix. Creators of the storylines flesh them out with plausible progressions from current conditions and integrating other less important uncertainties. Modeled after Peterson et al. (2003b)

Though the scenarios are defined by the interplay of the two selected axes, all of the drivers brainstormed in the assessment phase should receive some attention in one of the storylines. The individual storylines should include more uncertainties than the two chosen for the uncertainty matrix (Oglivy and Schwartz 2004).

One of the key challenges of the scenario planning process is communicating the scenarios with potential users. To help them to be remembered, each storyline is given a name that evokes the key features of that scenario (van der Heijden 1996).

There is no magic rule as to the number of scenarios that should be created. Wollenberg et al. (2000) suggest that even though users can only compare a limited number of storylines at a time, many can be created during a scenario planning process. Other authors argue that a small number of scenarios—usually three to five—is more useful than a plethora of them (van der Heijden 1996, Peterson et al. 2003a). If three scenarios are created, the main uncertainties should be varied. “If the themes are only different values of the same uncertainty, people tend to select the middle one as the most desirable scenario”

(Wollenberg et al. 2000: 72). Using fewer than three scenarios overly limits learning opportunities (van der Heijden 1996, Peterson et al. 2003a). Each of the storylines created should be unique in order to maximize the number of factors that can be explored (Peterson et al. 2003a). The testing step, during which scenario authors verify plausibility and consistency, should include an examination of the scenarios to ensure their uniqueness.

Including unlikely scenarios and those with extreme implications can help stakeholders and planners to overcome biases about the ways that we think about the future (Futures Methods and Issues: A technical annex to "Beyond the Horizon: Protecting the Future with Foresight" 1995, Wollenberg et al. 2000). Wollenberg et al argue that "As the intent of scenarios is not to predict the future but to improve abilities to adapt to it, [...] extreme elements should not be considered 'unrealistic'" (2000: 71). Oglivvy and Schwartz (2004) endorse including what they call a 'wild card' scenario:

In scenario exercises built around a matrix of four logically contrasted scenarios, we will sometimes include a fifth 'wild card' scenario that takes into account a dramatic yet relevant surprise that doesn't fit neatly into the matrix. (14)

The wild cards they suggest including are the types of discontinuities from current trends that can fundamentally change the system, and the available management options.

Scenario analysis is a powerful tool for creating plans robust to a variety of potential futures, but is not a universal solution for planning conundrums. The scenarios are only as complete as the authors make them and the planning process is therefore still limited by bounded rationality. Additionally, the process is only as effective as the storylines are convincing; if readers consider them so extreme as to be unbelievable, they do little to expand the scope of the planning process. As such, authors face a catch-22; if extreme elements are left out of scenarios, readers are not challenged to consider a wide range on possible futures, and if they are included readers may not consider the storylines credible.

Readers of the storylines must realize that scenarios are in no way meant to be predictions of future events. Even if the future were to resemble the beginning of one of the storylines, subsequent events are unlikely to unfold as they did in the scenario. During

the first decades in which scenario planning was used by industry professionals, some users of the technique became disenchanted when they realized the process has no predictive abilities (van der Heijden 1996). If misunderstood as predictions, the technique will quickly lose credibility amongst users, rendering it a powerless process.

CHAPTER III

METHODS

This thesis utilizes a scenario planning method to create four storylines that represent plausible futures for the Jackson, Wyoming/ National Elk Refuge social-ecological system. In order to understand how the system has developed to date, a literature review was conducted on the history of the system covering what is known of about Native American interactions with the ecosystem up to contemporary developments. The current state of the ecology and economy are also characterized so as to provide an accurate starting point for the scenarios.

Following the model by Peterson et al (2003b), I created a flow chart showing some of the strongest connections between components of the social ecological system in order to understand how changes in system drivers could affect various components of the ecosystem and the economy (See *Figure 10 Map of interconnections in the Jackson/ NER social-ecological system*). Using this model, I selected two factors that are at best weakly controllable from within the system due to physical and legal restrictions, but which have the potential to affect change in both the ecology and the economy- wildlife disease and the re-establishment of wolves in the southern Greater Yellowstone Ecosystem.

Wildlife disease and wolf repopulation were selected as the central variables for the scenario analysis for four main reasons: 1) their controversial nature amongst interested stakeholders; 2) their potential impact for numerous stakeholder groups; 3) the attention they receive in scholarly journals as potential drivers of change; and 4) the limited ability to control both variables from within the system.

Once the variables were selected, I conducted a literature review on both chronic wasting disease (selected as a disease that could have significant impact on the system) and the social and ecological effects of wolf repopulation. The current state of knowledge on

each was explored in order to provide necessary background information and establish a range of possible values for the respective uncertainties. The discussion of each uncertainty concludes with an explanation as to why the future effect of that variable is not predictable and should be treated as uncertain. These literature reviews are in the “Uncertainties” section of Chapter 4: Analysis of the National Elk Refuge/ Jackson, Wyoming Social Ecological System and begin on page 68.

The scenarios focus on factors that are not completely controllable by stakeholders in order to highlight the potential for outside drivers to fundamentally change the system. Disease can be at best marginally controlled by manipulating management strategies, but as the section on the history of the system explains, management is subject to intense political pressures from multiple sides. Wolves are protected in the area and management of the species is constrained by state and federal law. Additionally 97% of the land in Teton County is federally managed, either as national forest, wilderness area, wildlife refuge, national park, or other public land (Teton County Comprehensive Plan, 2002), limiting the amount of control local stakeholders have over wolf management. Though both disease and wolves can be influenced by management, from the perspective of local stakeholders neither is controllable. This thesis is intended as a tool to help stakeholders evaluate management options in face of potential extrinsic variation because a given surprise’s effects on the social-ecological system is mediated by management. A system managed for resilience might allow unanticipated events to pass with little effect whereas surprises might completely reorganize simplified ecosystems. To maximize its utility this thesis therefore focuses on variables that are not controllable from within the system.

Ranges of possible values for the impacts that disease and wolf repopulation could have on the system were developed based on what is known about both variables and the interconnected nature of the system. Unique combinations of several of these plausible values for the two central uncertainties were used to create end point conditions for each of three scenarios. Storylines were then constructed by creating a series of possible events that could lead to the described endpoints. Other uncertainties were integrated into each of

the storylines to flesh them out and draw attention to other possible factors that could impact the system. Including change in variables other than disease and the effects of wolves better represents reality in which many or all drivers are likely to be dynamic. A fourth wildcard scenario is used to highlight the fact that a great deal of uncertainty remains about chronic wasting disease and its potential to affect species other than deer and elk. The number of scenarios, four, was selected to alert stakeholders to a diverse range of potential futures without providing so many as to be confusing.

The scenarios were evaluated for consistency with the current knowledge on the central uncertainties to verify that no events regarding the key factors are currently believed to be impossible. The literature reviews on chronic wasting disease and the effects of wolves highlight the uncertainties that remain on their potential impact on the system. The scenarios focus these knowledge gaps and the lack of predictability in order to help stakeholders take that unpredictability into account when making plans and evaluating policies.

In order to best evaluate the current management regime, all scenarios assume that the current feeding and brucellosis vaccination programs continue into the future. A twenty year horizon was chosen because of a recognized potential for chronic wasting disease and local wolf reestablishment to influence system dynamics in the near future.

CHAPTER IV

ANALYSIS OF THE NATIONAL ELK REFUGE/ JACKSON, WYOMING SOCIAL- ECOLOGICAL SYSTEM

The first section of this chapter provides a history of the Jackson Hole social-ecological system and a description of the current state of the system. I explore the current management regime and competing stakeholder claims on the ecosystem. This section explains the political reasons for the current ecologically questionable elk management regime. Additionally, the history and the current state of the system are explored to provide an accurate starting point for the scenarios.

The "Uncertainties" section provides literature reviews on the two focal uncertainties: chronic wasting disease and local wolf repopulation. The current state of knowledge on each is explored and gaps in the knowledge are highlighted. The literature reviews also explain how each factor is capable of disrupting the social-ecological system and why the potential effects are uncertain.

History

Native Americans and Early European-American Explorers

The Washburn party, one of the first European-American exploratory groups to enter the Yellowstone region (1870), viewed the area as a pristine wilderness, free from the influence of human hands (Spence 1999). These first explorers assumed that the Indians "would give . . . wide birth [to such places], believing them sacred to Satan" (cited in Spence 1999: 42). In fact however, native groups, including the Crow, the Shoshone and the Bannock Indians spent significant amounts of time in the area. As horses became more common many other groups of Native Americans traveled through to get to bison hunting

and trading areas (e.g., Nez Perce, Salish, Kalispell, and Cour d' Alene) (Spence 1999: 48). Native Americans occupied the Yellowstone ecosystem since the end of the last ice age and adapted to the conditions there. Yellowstone was not untouched by human hands when white settlers' eyes first saw it, but rather it had evolved along with the people who had been there for thousands of years. As the historian Mark Spence describes it, "Over the course of several millennia, climatic and environmental changes in the Yellowstone area, along with the cumulative effects of long human impact, led to commensurate adaptations in native lifeways" (Spence 1999: 43). The people of the Yellowstone plateau helped to shape the ecosystem there, and in turn were shaped by that ecosystem. Their very cultures and traditions evolved in step with the ecosystem as it was when first seen by white explorers.

Though there were numerous indigenous groups who occupied the area occasionally, the Shoshone Indians likely had the longest presence there. The Shoshone were not a single group, but rather represented "a loose assortment of communities tied together by marriage, culture, and language" (Spence 1999: 45). Some, the Kutsundeka, were primarily buffalo hunters and relied on horses acquired during the early 18th century; others, the Agaideka, sustained themselves primarily on fish. The Tukudeka did not adopt the horse, but instead retained a more sedentary lifestyle and predominately hunted sheep, supplemented with elk and small mammals, as well as plants gathered in the region (Hultkrantz 1974, Spence 1999). "The highly complex, highly diverse system of plants and animals (including man) has maintained a natural balance over thousands of years, even while undergoing constant change" (Janetski 1987).

To understand how they were able to live in an inhospitable place such as Yellowstone and co-exist with the wildlife requires an exploration of their culture. Anthropologist Gary Wright explains that "cultures, including prehistoric ones, are not simply ways of getting food [... t]hey relate us to the world with which we interact" (Wright 1984: 40). The Shoshone had intricate stories to explain the world around them. Their stories reflect that they understood their absolute dependence on their environment:

[T]he same kinship structure found within the local group was extended to the natural environment. [...] The myths describe the world in terms of observable phenomena. [...] These, then, are symbols on a deeper plane, of a land ethic. It is the realization of a basic kinship with the land itself, a oneness with the environment and the impossibility of survival if this interrelationship is rejected. For the People, to be cut off from their kinsmen, to deny the earth, was to perish. (Wright 1984: 40)

The Shoshone understood that they were dependent on the earth, and they treated its creatures as kinsmen. The existence of their culture depended on the continuing health of the surrounding ecosystems. As such, their culture evolved along with the ecosystem and they were able to rely on wildlife resources without decimating them.

When native people were removed from the supposedly “pristine” and “untouched” Yellowstone area they retained the right to hunt there in the treaties they signed with the US government. Native groups continued to hunt in the Yellowstone region until 1883 when all hunting was banned within the National Park borders in violation of Native rights. Because of limitations on hunting elsewhere, native hunting pressure in the Yellowstone Ecosystem actually increased at the time (Spence 1999). By 1917, approximately 75% of North America’s elk were in the Yellowstone region (Smith 2001) – market hunting had decimated the herds where they had been exposed to it and healthy populations only thrived in remote regions. Native people, though increasingly dependent on the Yellowstone elk at the time, successfully co-existed with the elk.

European-American hunters did not have a religion or a history that connected them with their new-found surroundings. For its early managers, “ecological thinking in Yellowstone was bounded by strong preservationist traditions in big game management that focused on single species, an emerging range management paradigm, [and] a cultural ethic of control over nature...” (Pritchard 1999: 24). The managers emphasized controlling and improving upon nature for higher human purposes, and focused first on improving upon the park’s aesthetics for tourist purposes (Pritchard 1999: 25). This approach was fundamentally different from that taken by native groups in the area, and led to the simplified and vulnerable ecosystems that we have today.

Yellowstone's early superintendents believed that Native Americans did not regularly use the park and expelled them from the area. Realizing that their own culture's market hunting had nearly driven bison to extinction and seriously reduced elk numbers and misunderstanding Indian practices, they dispossessed the Native Americans of their land and their rights to practice subsistence hunting. The Native Americans in the Yellowstone area were bound to their surroundings by culture and tradition. They had evolved an understanding of the world that allowed them to co-exist with large, healthy, and wild herds of animals. The market economy brought west by settlers was unable to reach that balance as its practitioners focused more on profit than a sustainable relationship with the resources they were using. In the face of drastic reductions in wildlife populations managers utilized intensive management techniques borrowed from industry and agriculture. The herds we have today, the result of a century of this type of management, are precariously concentrated and oversimplified.

Elk Become a Commodity

The shift from the native Shoshone, Crow, and Bannock cultures to the European-American culture precipitated fundamental changes in how elk in the Yellowstone area were valued. Whereas the native cultures treated elk as equals, to be respected as brethren, elk counted for little more than a commodity in the market economy brought to the region by European-Americans.

James Scott, in his book Seeing Like a State, argues that modern governments categorize and homogenize nature in order to control it from central locations. Scott argues the very language of nature hints at how it was (and still is) perceived: "... utilitarian discourse replaces the term 'nature' with 'natural resources,' focusing on those aspects of nature that can be appropriated for human use" (Scott 1998: 13). Elk, which Native Americans who depended on them considered to be siblings, became units to be counted and manipulated under the European-American management regime. Simply put, elk became commodities. Elk management became a mathematical formula: if you want more elk, you remove their predators and other factors limiting their survival. The problem is, as Scott argues, "[t]he necessarily simple abstractions of large bureaucratic institutions [...]"

can never adequately represent the actual complexity of natural or social processes" (Scott 1998: 262). The current elk management problems come about because the centralized control over nature requires oversimplification of ecosystems and processes. Elk have been managed as commodities since European-Americans took control of the region in the late 18th century.

Yellowstone became the world's first national park in 1872 and the National Park Service was created in 1916. The enabling legislation directed that the parks were to remain "unimpaired." Early managers did not interpret this designation to preclude heavy handed management, which they believed could improve upon nature. Landscape architects (as they later came to be called) dominated the early National Park Service staff; biologists were nowhere to be seen (Sellars 1997: 69-75). Friedrich Law Olmsted, the landscape architect who built Central Park in New York and re-engineered Niagara Falls to look more 'natural,' was influential in crafting the legislation that enabled the National Park Service. Yellowstone was heavily managed for aesthetic purposes during those early years. Park managers trapped and poisoned predators, and stocked non-native fish species, all of which they interpreted to fit within the goal of leaving the park "unimpaired" (Sellars 1997). Managers saw the draconian removal of predators as improving the beauty and utility of the park for its visitors because it was thought to lead to an increase in desirable species, such as elk, bison, trout, and even the ever popular hand-fed bears. Similarly, Steven Mather, director of the National Park Service from its foundation in 1916 until 1929, advocated building golf courses in Yellowstone and Yosemite to encourage visitors to stay longer (Sellars 1997: 62-63). Livestock grazing was allowed, providing it did not interfere with tourist camping (Sellars 1997: 37). Managers commoditized nature as a tourism resource and manipulated to provide ever increasing returns.

The decimation of wildlife elsewhere made Yellowstone more valuable as a source of treasured wildlife species. The westward expansion of the market economy had severely threatened the viability of bison and recent extinction of the passenger pigeon was fresh on peoples' minds (Pritchard 1999: 8). Memories of these events (the disappearance of a formerly abundant species and the near extinction of the large, highly valued bison) guided

early elk management. The first priority for Yellowstone's managers was to eliminate market hunting pressures that caused the decline of wildlife species outside of park boundaries.

Although the park's establishment in 1872 clearly outlawed hunting 'for the purposes of merchandise or profit,' hunters took large numbers of elk and other animals in the park. In 1875 [...] market hunters [...] had killed four thousand elk (possibly in the Lamar Valley area) plus large numbers of bighorn sheep, deer, antelope, moose, and bison, taking for the most part only tongues and hides. (Pritchard 1999: 9)

In response to this report and others of many thousands of elk poached within park boundaries that same year, all hunting, including subsistence hunting by native groups was prohibited in 1883. Yellowstone was seen as a refuge where the elk would be free from the supposedly artificial pressure of hunting. In 1886 the US Army was dispatched to Yellowstone to protect the herds (Pritchard 1999).

Elk herds within Yellowstone's borders were managed in a very mechanistic way. "Elk production" was maximized following an agricultural model. Managers typically started with a number of elk they wanted in a herd, and then set about figuring out how to support a population of that size on the available land (Pritchard 1999: 19). When grazing experts suggested that a lack of winter range was the factor most limiting the elk herd populations in Yellowstone, the answer was to feed the elk. Historian James Pritchard describes the situation as follows:

Wildlife problems were seen as relatively straightforward. If the elk were being slaughtered, the park should protect them. If the elk appeared to be close to starvation, the park must feed them. Because the American bison was on the brink of extinction, the park propagated remnants selected from several herds and guarded the results carefully. When sportsmen wanted abundant fish throughout the Rocky Mountains, federal and state agencies established fish hatcheries (including one at Yellowstone) to propagate and distribute trout. In each instance managers raced to catch up with a situation thrown in their laps. (Pritchard 1999: 25)

Managers dealt with wildlife crises in very mechanistic ways because animals were seen as commodities and ecosystems more as factories for the production of those commodities than as complicated natural systems important in their own right. The crises that came about due to market pressures and ecological simplification inspired managers to

further manipulate natural systems to optimize production of game animals. Desired species (such as elk and trout) were bred and undesirable ones (predators) were removed from the system. "The 'scientific' justifications for elimination of predators involved simple economic calculations. Any loss of game animals was too much to bear" (Pritchard 1999: 33). Predators did not hold the commodity value that did elk.

Though commonly viewed as an important commodity, different groups valued elk for disparate reasons. Elk were cherished in Yellowstone for their value in increasing tourist experiences. They were prized as an export commodity to re-stock herds and provide specimens for zoos. Hunters in Montana wanted managers to let elk follow their natural migration out of the park so they could be hunted. Managers, however, sought to prevent that fate for their beloved elk: "Vernon Bailey, chief field naturalist for the Bureau of Biological Survey from 1887 to 1937, wrote at the time that the 'present policy of raising elk in the Yellowstone Park to be killed as fast as they come out does not appeal to most of us as a wise conservation policy'" (Pritchard 1999: 18).

Another debate raged over the purpose of lands within Yellowstone. The ranching community, allowed to graze their animals within the park's borders, wanted more of the land dedicated to livestock.

Henry S. Graves, a local official of the U.S. Forest Service who later became Gifford Pinchot's successor as director of the bureau [...] thought a 'very serious question of public economics arises as to how much of these Yellowstone ranges should be devoted to domestic stock and what part should be held purely for the propagation on elk.' (Pritchard 1999: 19)

The Yellowstone ecosystem was managed for many competing economic purposes: tourism, hunting, ranching, and others. It was not managed as the biological preserve that many people now view it to be and cherish for that reason. Each group had its own demands on the lands and the animals that comprise the ecosystem. Some of those interests valued elk; others, such as ranching, prioritized public access to land that elk needed for forage. The newly introduced market system created multiple competing demands on the Yellowstone ecosystem, each of which required manipulation of natural systems to optimize their efficiency toward some desired ends.

The predator removal policy, artificial winter feeding, and elimination of native hunting practices quickly led to problems of elk overabundance. As early as 1907 elk were shipped from Yellowstone to zoos and parks across the country to re-establish herds in areas where they had been reduced or extirpated (Pritchard 1999: 15). It is estimated that around 13,500 elk were shipped from Yellowstone to locations around the country and several foreign destinations (Robbins et al. 1982: See Figure 7 Destinations of live elk shipments from Yellowstone National Park, 1892-1967 for a map representing the shipments). Managers also grew dependent on direct herd reduction (i.e., killing) to control the animal populations. Approximately 67,440 elk were culled from the herd between 1934 and 1967, when the practice was ended (Pritchard 1999: 138). Elk in Yellowstone were actively managed as a breeder population and used to stock herds already decimated by market hunting throughout the country (Pritchard 1999: 17). They were administered as if they were livestock; they were fed, their populations controlled, and they were trapped and shipped to other locations as needed.

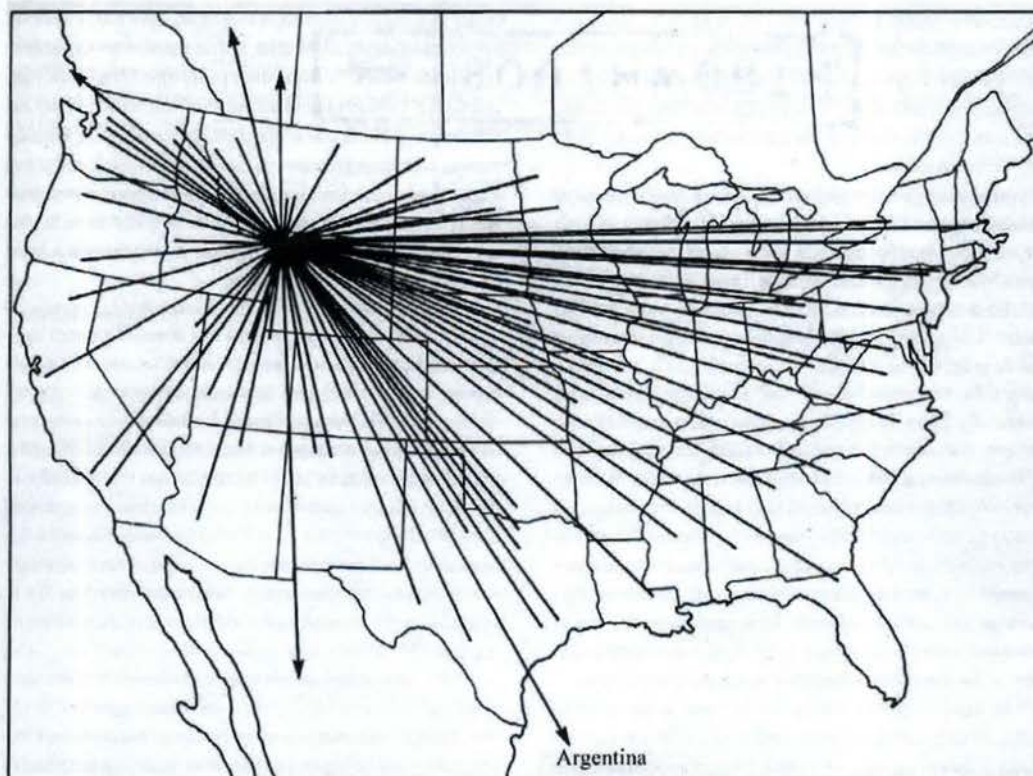


Figure 8 Destinations of live elk shipments from Yellowstone National Park, 1892-1967

Source: Robbins et al. (1982).

The National Elk Refuge and its Feeding Program

At the southern end of the ecosystem, the town of Jackson, Wyoming was being developed in a geographic bottleneck. Some authors suggest that prior to European-American settlement in Jackson, most of the elk migrated south to more favorable winter range in the Green River basin, the Little Colorado Desert, and the Red Desert (see Smith et al. 2004).

By 1895, market and “tusk” hunting, barbed wire fences, and retaliation for conflicts with livestock operations decimated numbers of these migrants that traveled up to 150-450 kilometers (100-300 miles) between their seasonal ranges. (Smith et al. 2004: 15)

There was likely a small herd of elk that stayed in the Jackson Hole area year round, though it is not clear how large this population was (Smith et al. 2004). By 1909,

most of the potential winter range for elk in the Jackson Hole bottomland was being occupied by ranches and the grass was put up for livestock, rendering it unavailable for the elk (Smith et al. 2004). See *Figure 9 Locations of original homesteads and other developments on the National Elk Refuge*. The State of Wyoming began feeding elk to help protect the remaining elk after a series of harsh winters led to large elk winterkill. The combination of available artificial feed, the use of fences, the construction of the town of Jackson, and hunting led to an end of the elk migration to the south by 1913 to 1917. "The winter distribution of the southern Yellowstone herd, now known as the Jackson elk herd, was reduced to the Jackson Hole, Gros Ventre, and Buffalo Fork valleys" (Smith et al. 2004: 16). With time the elk became accustomed to the feeding program and they adjusted their natural migration patterns to spend the winters on the feedgrounds each year, whereas formerly they only congregated around Jackson in severe winters. Managers assumed the elk would only come to the feedgrounds during abnormally harsh winters, but as it turns out they abandoned their usual winter range in favor of the feedlines (Wolfe et al. 2002: 595).



Figure 9 Locations of original homesteads and other developments on the National Elk Refuge

Note the location of Jackson in the lower left corner. Much of what is now the Refuge was once used for ranching. Adapted from Smith et al. (2004)

In 1912 the federal government purchased 1,760 acres of private lands just north of Jackson, Wyoming and thus established the National Elk Refuge. There is no mention of feeding elk in the Act of Congress that created the refuge, but rather "...feeding elk became policy out of repeated practice" (Smith et al. 2004: 18). Since the early days of the Refuge, managers have fed elk on the refuge in order to maintain a large population despite the fact that the town of Jackson cut the herd off from 75% of its historic winter range (Smith 2001). An agricultural model was used to have the best of both worlds: abundant elk *and* development in their migration corridor.

Elk were forced to stay in the Jackson Hole bottomlands when development interrupted the elk's natural migration routes to winter food sources, bringing them into competition with livestock for hay (Boyce 1989). Rather than killing the elk to end the conflict, as was done elsewhere, the residents of Jackson wanted to maintain a large herd (Smith et al. 2004). One early author attributed the attitude to a recognition that the elk were a valuable resource, helping to support a larger human population in the area than could survive without them (Preble 1911, cited in: Smith et al. 2004). Elk were important to the Jackson economy from the beginning of European-American settlement.

When development came into conflict with the elk population, the answer was not to remove the barrier, but rather to optimize elk production—to use managerial parlance—on the available land. Analogous to fisheries managers in the Pacific Northwest who believed they could have salmon without rivers, by feeding elk on the refuge and removing predators, managers believed they could sustain large elk populations despite development of their winter range.² The agricultural approach to elk management was successful towards those ends, as the Jackson Herd population count is currently around 16,000 animals, about half of which winter on the NER (Clark 2000). Bruce Smith (2001), formerly a refuge staff biologist, summarizes the history of the refuge and its feeding program. The Wyoming Department of Game and Fish administers 22 elk feed grounds

² "Salmon Without Rivers is the title of a book by Jim Lichatowich that describes how fisheries managers in the NW have relied on hatcheries for the past century to support salmon populations when rivers were dammed and degraded. Despite research that shows the hatcheries actually damage wild salmon runs, managers are loathe to question hatchery effectiveness or admit their failures. (2003)

and the National Elk Refuge is managed cooperatively by the US Fish and Wildlife Service and the state of Wyoming. A 1974 agreement between the two agencies stipulated that a maximum of 7,500 elk be maintained on the National Elk Refuge each winter. Between 1994 and 1998, however, an average of 9,200 elk used the refuge annually. Elk on the NER consume 28 tons of pellet alfalfa per day for an average of 79 days each year. The feeding comes at a great economic expense to the agencies, which share feeding costs. Exclusive of administrative and biological monitoring expenses, it cost \$35 per elk per winter to feed the elk on the refuge. Just to distribute feed to 7,500 elk costs \$337,488 per winter. Interestingly, sale of hunting licenses does not cover the cost of feeding and administering elk in Western Wyoming. Smith notes:

The revenue generated from sale of elk licenses in 1998 was \$7,770,000, but costs of elk management were \$8,820,000. Costs of elk management west of Wyoming's Continental Divide, where the state and federal feedgrounds are located, totaled \$2,758,000 in 1998 compared to license revenues of \$1,846,000. (Smith 2001: 179)

Much of the revenue from hunting is not from the direct sale of licenses, however, and is dispersed amongst various sectors of the economy, including outfitters, the service industry, and others.

The current management scheme supplies hunters with abundant elk, tourists with world class wildlife watching from the town of Jackson Hole, and provides the town with a sense of pride in their wildlife herds. Multiple stakeholders benefit from the large populations that result from the policy of feeding elk on the NER. H Bradley Kahn (2000: 144) identified a list of twenty stakeholder groups who are interested in management issues on the refuge, including: state and federal governmental agencies; the U.S. Department of Agriculture's Animal and Plant Health Inspection Service; hunting, ranching, and environmental advocacy groups, tourists, Native Americans, and others. Each of these groups has vested interest in the elk and their well being, but each defines a healthy elk herd in its own manner. In so doing, each group frames management debates in terms of how changes will affect them. The early disputes over management techniques (e.g., between ranchers, hunters) only became more complicated as the population has grown and outside people and organizations have become more interested in the wildlife management

issues. As one author argues: "Like all natural resource management, managing elk can be reduced to questions of 'How will they be used?' and 'Who gets to decide?'" (Clark 2000: 171) Any proposed change in management strategies will benefit some constituencies and come at an expense to others (Kahn 2000).

Brucellosis

Feeding elk helped bring the North American population from an estimated 50,000 animals at the turn of the 20th century to their current total of approximately 1 million animals (Smith 2001). As mentioned earlier, the feeding program has an unfortunate and unintended consequence: the dense concentration of animals each winter causes increased incidence of disease. Elk on feed lines spend more time muzzle to muzzle than their wilder counterparts that winter elsewhere, providing ample opportunity for disease transmission. Brucellosis is a disease affecting domestic and wild ungulates that causes abortion of the first calf born to an affected female elk. Brucellosis infection rates for adult female elk associated with Wyoming State feedgrounds have averaged 34 percent over the past 31 years, and those that winter on the NER have averaged 36 percent over that same period (Clause et al. 2002). Bruce Smith notes the importance of feeding programs in the persistence of this disease. "[O]ut of a million elk in North America, only those associated with the winter feeding programs in western Wyoming and adjacent eastern Idaho maintain this disease at any significant prevalence" (2001: 184). Brucellosis was first identified in elk on the NER in 1930 – the impressive elk population recovery there occurred while the herd was affected by the disease, demonstrating that it does not pose a dire threat to elk recruitment (Thorne 2004). Refuge biologists estimate that the calving rate may be reduced by 7% compared to what it might be absent brucellosis, but the number of elk residing on the NER is consistently above target levels. Though not a serious threat to elk herds there, the presence of the disease which is exceedingly rare in elk that are not artificially fed serves as an indicator of the unhealthy conditions that exist on the feedgrounds (Smith 2001).

The State of Wyoming vs. the United States

Management of the National Elk Refuge is directed by the US Fish and Wildlife Service and the federal government owns the land that comprises the refuge. The State of Wyoming has made legal arguments that it owns the elk on the NER because they live within state boundaries, though the courts have repeatedly decided that the federal agency must share the management responsibilities when the proposed activities are not contrary to the mission of the National Wildlife Refuge system. Disputes over management strategies on the NER have manifested themselves in recent years in the form of multiple lawsuits (See State of Wyoming v. United States 1999, State of Wyoming v. United States 2002), an ongoing NEPA analysis of the feeding program (Loomis and Caughlan 2004b), and a recent and highly contested decision to vaccinate elk on the refuge with Strain 19 *Brucella abortus* vaccine. This vaccine, developed for cattle, is of questionable efficacy in elk (Roffe et al. 2004).

Its lack of effect on elk population dynamics does not portend the political debacle brucellosis has created. Wildlife biologist Bruce Smith notes that: "For a disease that is relatively benign in elk, brucellosis has whipped up a firestorm that has spread to the highest levels of state and federal government" (Smith 2001: 183). In 1989 the WDGF began vaccinating elk on the National Elk Refuge with the Strain 19 vaccine on a trial basis with the blessing of the USFWS. The program lasted for only three years before the state halted the program, claiming that the low level of cooperation from the federal agency reduced the cost effectiveness and benefits of the program (See State of Wyoming v. United States 2002). Since that time the FWS has refused to vaccinate elk on the refuge and declined offers by the State of Wyoming to undertake such a program at its own expense.

The WDG&F sued the FWS in 1998 to force the federal agency to allow the state to re-instate a brucellosis vaccination program on the refuge. The FWS asserted that there was insufficient evidence that vaccination was effective, and that the NER was taking other steps to minimize the prevalence of brucellosis, such as altering the type of food delivered and the mode of delivery to minimize the time elk spend on the feedlines. The state made

the following claims in its lawsuit: the federal government overstepped its authority by refusing to allow the state to vaccinate, and that the state has "...inherent sovereign authority to manage, control, and regulate diseases in wildlife and domestic animals for the health, safety and protection of its citizens, its domesticated livestock and its free roaming wildlife" (State of Wyoming v. United States 2002). The Federal District Court in Cheyenne found for the federal government, so Wyoming appealed the decision to the 10th Circuit Court of Appeals. The appellate court found that the federal government, through the Fish and Wildlife Service, failed to take proactive steps toward eradicating brucellosis, putting the state at risk of financial harm if Wyoming were to lose its brucellosis-free status (as it did in February 2004). The case was remanded back to the District court, which required an Environmental Assessment of the proposed vaccination. The Fish and Wildlife Service determined that vaccination would have no negative effects (USFWS 2003b). Under the terms of the court decision, the State of Wyoming is allowed to vaccinate elk if it does not have negative environmental effects that are counter to the National Wildlife Refuge System mission. Neither the state nor the federal government was required to show that the vaccine is effective in preventing brucellosis. Vaccination commenced in 2003.

H Bradley Kahn argues that when the WDGF sued the NER for the right to vaccinate, "The lawsuit was fundamentally about power, as both the USFWS and WDGF were claiming the right to make decisions about how the elk are managed on the refuge" (Kahn 2000). The lawsuit is the latest embodiment of an ongoing states rights struggle for power and decision making authority. As explained by Tim Clark, "this agency's [WDGF] policies reflect the views of the governor, who espouses states' rights ideology and vehemently opposes the federal government ... The elk case is just one of many wildlife issues for which Wyoming Game and Fish – indeed many states in the West – contend with the federal government for authority and control" (2000: 174). As much as being about elk, the dispute over management is about a struggle for power and control between two levels of government. The same situation has arisen several times in recent years with federally managed lands in the Greater Yellowstone Ecosystem. Many in Wyoming resent

the reintroduction of wolves, enforcement of endangered species laws that limit land uses, as well as oil and gas development on ranch and forest lands – all decisions that local people see as handed down from an overly controlling federal government. In this setting, it is predictable that the dispute over elk management would be similarly bitter.

Many people on both sides of the feeding and vaccination debates care deeply about the well being of elk on the refuge. Long term residents of Jackson in particular have a sense of responsibility for the elk. The original European-American settlers in the Jackson Hole area felt a great pride for their elk herd and contributed to the effort to sustain the population. The local community provided much of the motivation behind the creation of the refuge. Community members directed its management (a local game warden was the original manager), gained financially by selling hay to the refuge, enjoyed reduced depredation on haystacks, and had a reliable source of meat. To further increase the fodder available to elk, managers hired local cowboys to maintain irrigation ditches. As Kahn points out, “Their efforts were recognized as being so significant that during World War II they were exempted from the draft so that they could continue producing hay for the nationally acclaimed Jackson elk herd (Kahn 2000: 156).” Local people played a critical role in the maintenance of the refuge, and therefore felt pride in assisting in stewardship of the growing elk population (Kahn 2000).

Through a series of interviews with stakeholders, Kahn determined long term residents feel that their control over and contributions to elk management have been usurped by outsiders, including the federal government. A pivotal event in the NER management history, for example, occurred in the 1960s when administrators phased out the use of locally grown hay in favor of more easily distributed and cheaper alfalfa pellets grown outside of the valley. This seemingly insignificant change meant local hay producers were unable to contribute in their accustomed manner to elk management and local producers no longer benefited financially from the elk management program. When the US Fish and Wildlife Service refused to allow the WDGF to vaccinate elk against brucellosis, some local people and their state representatives viewed it as a failure of the federal government to address an issue very dear to their hearts (Kahn 2000).

The NER, operated as part of the US National Wildlife Refuge System, has a well defined mission statement: to “provide, preserve, restore, and manage winter habitat for the nationally significant Jackson Elk Herd and habitat for endangered species, birds and other big game animals, and provide compatible human benefits associated with its wildlife and wetlands” (Cited in: Kahn 2000: 139). Built into the NER mission is the accommodation of human needs, provided they are compatible with other stated purposes of the refuge. The National Wildlife Refuge System Improvement Act of 1997 requires the USFWS to “maintain the biological integrity, diversity, and environmental health of the Refuge System,” including the NER (Cited in: Matson 2000: 101-102). The mandated goal of federal interests in NER management is the protection of the ecosystem, which includes elk, but is not defined exclusively by elk or the size of the herd.

According to Kahn (2000), the administrators in the FWS see vaccination as contrary to their mission. That agency instead proposes a four part plan:

- (1) increase and disperse available forage;
- (2) locate additional forage;
- (3) increase elk hunting to reduce elk populations; and
- (4) when proven safe and effective, implement a vaccination program (See: *State of Wyoming v. United States* 2002).

The federal agency’s plan is to take advantage of the fact that elk display lower prevalence rates when not fed. To combat the disease, they hope to reduce the time elk spend on feedlines.

The Wyoming Game and Fish Department, however, does not share the priorities of the federal agency, and it is these differences that led to the lawsuit over vaccination. Their stated position on brucellosis vaccination is as follows:

The Commission and Department believe that, if possible, brucellosis should be eliminated. However, without a vaccination-based brucellosis control program on the Refuge, brucellosis can only be partially controlled and can never be eliminated in the remainder of the Greater Yellowstone area. (Thorne and Reese 1998)

The agency has pre-defined what the solution will look like. Their reliance on medical and veterinary techniques to treat a problem that results from the spatial arrangement of animals stems from the overall department's mission statement. The Wyoming Department of Game and Fish mandate is to provide "an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife" (Cited in: Clark 2000). Each of the words in their mission statement speaks to the intensive management techniques the agency employs. As one author argues:

The department's model of elk management is largely an 'agricultural' one in which animals are fed on feedlots, vaccinated, and otherwise intensively managed like cattle in order to maintain the highest possible numbers for hunting since sales of hunting licenses brings in millions of dollars to the state annually and keeps its traditional constituents pacified. (Clark 2000)

The Wyoming Department of Game and Fish is essentially a political body, governed by a commission appointed by the governor, and answers to the people of Wyoming. The people of Wyoming want control over the wildlife there, and benefit from the annual hunt. H Bradley Kahn clarifies some of the influences on the state agency:

... because hunters represent a significant constituency and because the WDGF receives income from hunting permits, the agency advocates maintaining the herd at present levels. [...] Since WDGF receives a significant portion of its income from the sale of hunting licenses, there is a strong wealth incentive driving the process to keep elk populations high. (Kahn 2000: 147)

The state wildlife management agency is under considerable political and economic pressure to maintain large elk herds in the Greater Yellowstone Ecosystem. Maintenance of a large herd is essential for the WDGF. Because of the incentive structures behind it, the state agency's management goal is fundamentally different than that of the federal agency's with which it shares NER management responsibilities.

Following his interviews with stakeholders, Kahn concluded local people fought for the creation of the refuge because:

Many people felt a moral obligation to feed the elk since their population decline had resulted from human causes. This ethical belief still motivates the supplemental feeding program today, and thus, rectitude is an important motivation for the management of the elk herd. (Kahn 2000: 144-145)

This is true for local people, the WDGF *and* the federal agencies that share in management decision making; most people involved believe their approach to be the best one for the elk. Underneath the state versus federal government power struggle lies a fundamental problem that prevents resolution of management disputes: the stakeholders define the problem differently. All involved claim they want healthy elk herds, but the state defines a healthy herd as a large herd whereas a healthy herd to the USFWS is one that contributes to the ecosystem as a whole. Each stakeholder has a different idea of what the elk are “for,” therefore it should be no surprise that the proposed solutions vary so drastically.

Tim Clark argues that: “Since goals for management of the Jackson Hole elk herd have not been agreed upon and since problems are defined only in relation to goals, different agencies and interest groups see different problems” (Clark 2000: 172). Hunter and outfitter groups wish to maintain the feeding program because it leads to large elk herds that must be culled by a yearly hunt to keep the population down. If vaccination is perceived as a way to maintain large herds, they support that (Kahn 2000). Ranchers support feeding on the refuge because it prevents elk from foraging on their lands. Cattle ranchers have had significant economic incentive to support elk vaccination because of a perceived possibility that elk could transmit brucellosis back to cattle, the original host of the disease. Cattle in Wyoming were recently diagnosed with brucellosis, causing the US Department of Agriculture to revoke their brucellosis—free status and mandate restrictions on interstate cattle shipments. The Wyoming Agriculture Department Director John Etchepare estimated that the testing APHIS mandated when the state lost its brucellosis-free status could cost Wyoming ranchers as much as \$1.6 million per year (Black 2004). These groups support vaccinating the elk because they perceive it as being a step towards eradication of the disease. Interestingly, the elk deemed to be the source of infection for the diseased cattle that caused the state to lose its brucellosis class-free status were vaccinated on a WDGF feed ground.

Both sides of the debate over vaccination on the NER cite epidemiological studies to back their position. Individual studies do not contradict one another in any fundamental ways. Rather, the studies cited set out to answer different questions. The state cited studies

that demonstrated calf loss decreased as a result of vaccination, and the FWS looked at the state's statistics to argue that disease prevalence on state feedgrounds did not significantly decrease due to vaccination.

The WDGF states their case for vaccination as follows:

By the early 1990's, Wyoming reported that its vaccination program had resulted in a seventy percent calving success rate for vaccinated elk, as compared to a thirty percent calving success rate for unvaccinated elk [...] By 1998, the State was vaccinating elk on twenty-one of twenty-two state feed grounds without notable adverse consequences (State of Wyoming v. United States 2002).

Their studies show that calving rate increases when the animals are vaccinated, but fail to mention that elk on the state run feedgrounds, which are vaccinated, continually suffer high prevalence rates (see: Clause et al. 2002). Contrary to preventing brucellosis, vaccination allows managers to feel they are taking steps toward eradication of the disease without tackling the difficult question of whether feeding – an act without which the disease would likely drastically diminish and perhaps disappear altogether – should be phased out.

Refuge staff biologists point out that the NER did not vaccinate elk during the winters of 2001-02 and 2002-03, and seroprevalance was 18 percent and 17 percent during those winters, respectively – far lower than the 37% average observed for the western Wyoming feedground complex since the 1970s (Smith 2003). The biologists suggest part of the low brucellosis rates on the NER may be the result of feeding methods employed by managers there. Smith and Roffe (1997) note that elk on the NER experienced a significant drop in brucellosis prevalence after managers switched from feeding a combination of long hay and pellet hay to using pellet hay exclusively.

Fish and Wildlife Service administrators hired several biostatisticians who analyzed the data from WDGF studies to support their claim that vaccination is ineffective. "The results of the studies found no significant effect would result from the use of the vaccine. As a result, the NER gained valuable knowledge in their case against WDGF" (Kahn 2000: 146). The FWS repeatedly stated they were unwilling to vaccinate unless the state were able to show that the vaccine was effective in reducing disease prevalence. The state

alleged that the federal agency would not allow vaccination to occur until they had “near perfect data” to show that it was effective (Thorne and Reese 1998).

The State of Wyoming was under immense political pressure to demonstrate that it was taking significant proactive steps toward brucellosis eradication. In a series of correspondences, the state pleaded for help from the FWS in their effort to eradicate brucellosis. In a letter to the director of the Fish and Wildlife Service in November 1997, the Governor stated that Wyoming had requested the USDA to conduct a “station review” (an audit of state animal husbandry practices) in order to appease other states who had threatened to stop accepting shipments of cattle from Wyoming because of fear that they might be brucellosis carriers. The USDA Animal & Plant Health Inspection Service dictated that Wyoming undertake a more extensive cattle testing program. The Governor asked the Director of the FWS to cooperate with the state in a wildlife brucellosis eradication program to finally do away with the wildlife brucellosis reservoir (State of Wyoming v. United States 2002). With the threat of economic sanctions against the state, Brucellosis truly is a crisis for Wyoming and its politicians.

Due to pressures from other states and the Department of Agriculture, Wyoming has to demonstrate that it is taking visible and proactive steps toward brucellosis eradication. People argue that brucellosis must be eradicated because of its threat to agriculture, so the state uses agricultural techniques to deal with the problem. This fits well in their established ranching style elk management regime. These factors lead the state to identify few possible ways to treat the disease: “Vaccination of elk to lower the prevalence of brucellosis is preferable to the alternative, but unacceptable, method of test and slaughter or doing nothing about brucellosis” (Thorne and Reese 1998). Being beholden to the hunting community precludes phasing out feeding, the ultimate source of brucellosis transmission. Doing nothing is not an option due to the threat of economic sanction from other states.

Combating brucellosis on the refuge vindicates the huge number of people and millions of dollars that have been spent in an effort to eradicate the disease elsewhere. Kahn argues that:

People within a variety of government agencies, including APHIS [Animal and Plant Health Inspection Services], state veterinarians, and the WGDF have spent their careers battling brucellosis. [...] When and if the disease is fully eradicated, the people who accomplish this task will receive a great deal of respect from the veterinary and livestock communities and the public. These same people have significant influence within the Wyoming state government, and it has been suggested that they are largely fueling the lawsuit [to allow vaccination]. (Kahn 2000: 147)

For the Fish and Wildlife Service, brucellosis is not a crisis and the agency has no investment in the vaccination program. The disease has not seriously affected elk populations and has little if any negative effect on other species under the agency's jurisdiction. The federal agency's mandate is to steward the ecosystem. Its primary concerns are for the species found on the refuge rather than the ranching or hunting communities. The 10th Circuit Court of Appeals decision centered on the extent to which the federal agency is required to cooperate with state priorities (*State of Wyoming v. United States* 2002). The court found that the National Wildlife System Improvement Act of 1997 called for a cooperative federalism, meaning that when management activities beneficial to state goals are not contrary to NWRS priorities, they must be implemented. As such, the courts dictated that the FWS conduct an environmental analysis to determine if vaccination would cause harm to the elk or preclude attainment of NER goals. When the FWS found that the vaccine would provide little if any measurable benefit, but would not actually harm the elk, the WDGF legally gained the right to vaccinate elk on the National Elk Refuge at the state's expense (USFWS 2003c).

The public, or at least those who commented during the Environmental Assessment of the vaccination plan, felt that it was a mistake to vaccinate on the refuge. Of the 305 comments on the plan from individuals, 303 were opposed to vaccination. The other two were neutral or gave no opinion. Of twelve NGOs that commented, ten opposed vaccination. All of the groups opposed were environmental or animal rights advocacy organizations. One NGO, the Wyoming Farm Bureau, whole-heartedly supported the vaccination. The Wyoming Wildlife Federation, a hunting advocacy organization, supported the vaccination plan but had strong reservations about its implementation (USFWS 2003a).

With rangeland becoming a scarce commodity, elk refuge administration has become what James Scott criticizes about agricultural approaches to management in his book Seeing Like a State:

Modern agricultural research commonly proceeds as if yields, per unit of scarce inputs, were the central concern of the farmer. The assumption is enormously convenient; like the commercial wood of scientific forestry, the generic, homologous, uniform commodities thus derived create the possibility both of quantitative comparisons between the yield of different cultivation techniques. (Scott 1998: 294)

The use of vaccine is essentially a cultivation technique. By framing the question in terms of which cultivation techniques are most effective, the WDGF presupposes that an agricultural approach is necessary. The agency examines only the ability of the vaccine to reduce disease prevalence and in so doing avoids asking more cutting questions. Tim Clark suggests that all the questions asked by various stakeholders boil down to these questions: "Should elk be concentrated on winter feed grounds (following an 'agricultural model'), or should we secure adequate winter range throughout the region and reduce or close down the feed grounds (following a 'wild animal model')? (Clark 2000: 172)" The public overwhelmingly argued that the elk should be managed in a more natural and less intensive manner than what is involved in vaccination (USFWS 2003a). These questions however are not expedient for an agency such as WDGF that depends on revenues from hunting licenses for its very existence.

Current Status of the Social-Ecological System

Ecology

The National Elk Refuge is currently 24,700 acres and home to a diverse set of species.

The present vertebrate fauna of the refuge includes 48 species of mammals, 175 species of birds, 3 species of reptiles, 4 species of amphibians, and 11 species of fish. All species of wildlife that inhabit the refuge, whether seasonal visitors, yearlong residents, or occasional guests, rely on refuge plant communities for food, water, and shelter to carry on life's necessities. (Smith et al. 2004: 3)

The flora upon which this diverse group of species depends includes 382 species of vascular plants and an unknown number of non-vascular plants (Matson 2000). Though initially created out of a desire to protect the elk herds and though it has been managed almost exclusively for their benefit, the National Elk Refuge is home to hundreds of other species. Under the National Wildlife Refuge System Improvement Act of 1997, the US Fish and Wildlife Service is required to manage wildlife refuges for the maintenance of all species found there (Matson 2000).

To date, management of the NER has primarily focused on elk, to the detriment of most of the biotic community types found there. Compiling data through literature reviews, observation, and interviews with managers, Matson (2000) summarizes the current state of the biodiversity found on the NER and concludes that the artificially dense elk herd found on the refuge has significantly altered the ecosystem and made it more vulnerable to invasion by exotic species. "Riparian trees and shrubs, aspens, and sage-grasslands have all declined in cover, abundance, regeneration, and structural diversity since the creation of the National Elk Refuge" (Matson 2000: 104). The fauna that depend on these vegetative communities have been similarly affected by management regimes designed with only elk in mind.

Economy

The individual contributions to the Teton County economy from the sectors of hunting/outfitting, tourism, and ranching are difficult to distill from census statistics because many people register their Jackson vacation homes as their primary residences for tax purposes. Many of the people who report living there for tax purposes actually spend relatively little time there and conduct business elsewhere. Additionally, 3,064 employees out of a total Teton County workforce of 12,838 commute from outside of the county because of inflated housing costs in the Wyoming resort community. As such, though accommodations and food services accounts for 31% of the local jobs, the 2002 mean per capita personal income for Teton County, WY was \$71,457, the second highest for any county in the nation (USA Counties IN Profile 2003). This inflated personal income average does not accurately reflect the income levels of the people who earn their money in Teton County. Given those caveats, farm work contributes only 2.4% of the total Teton County Wyoming and Idaho jobs (employment statistics for Teton County, Idaho are often included in discussions of Teton County, Wyoming because a large number of people commute from Idaho to work in the Wyoming county). Another 2.3% of the total jobs come from the agricultural services, forestry, and fishing industries (Loomis and Caughlan 2004a). Tourism contributes the largest number of part time and full time employment in the two counties: "Over 55% of the jobs in Teton County WY and ID are retail trade or service based, thus the local economy is highly dependent on tourism for its job base"(Loomis and Caughlan 2004a: 22).

Statistics regarding the numbers of tourists that come through Teton County annually are easier to come by because the National Park Service keeps detailed records on the numbers visitors and Jackson serves as the southern gateway community for both Yellowstone and Grand Teton National Parks. The user data from the parks, complemented by surveys of those visitors, lend some insight into the importance of tourism to the local economy. Between 1997 and 2001 an average of 2,644,316 visitors used Grand Teton National Park annually, 92% of which were non-local (Loomis and Caughlan 2004b). Loomis and Caughlan (2004b) conducted a survey of visitors to the

region to determine possible effects of the different options listed in the Environmental Impact Statement. As part of this study, a survey of Grand Teton National Park visitors found that wildlife viewing opportunities in general and the opportunity to view elk and bison in particular ranked as the second and third most important reasons for visiting the Jackson Hole area. When a multiplier is factored in for indirect income, tourism to Grand Teton National Park in the summer months accounted for nearly 30% of local income and 56% of local jobs (this study includes Teton County, Idaho as part of the local social system because that county serves as a bedroom community for many Jackson employees). The study found that implementation of any of the options that would result in decreased wildlife viewing opportunities would significantly decrease the amount of tourism dollars spent regionally. Adopting a no active management policy, meaning an end to feeding of elk and bison on the NER, would result in a loss of 2,894 jobs and \$62,200,355 from the local economy (Loomis and Caughlan 2004b). Survey recipients were told that this option would lead to a decrease in the number of bison that winter on the refuge from 600 to 200 and a change in the winter elk population from the current range of 5,000-7,000 animals (these numbers are from the survey and do not reflect the actual numbers observed on the refuge in recent years) to a range of between 2,000 and 6,000 elk. According to this survey, a decrease in the number of animals available for viewing will significantly decrease the number of visitors to the region (Loomis and Caughlan 2004a: 61).

These statistics regarding lost tourism dollars are based exclusively on a survey of locals and park visitors, and there is little research on how well surveys such as this one actually correlate to changes in visitation (Loomis and Caughlan 2004a). Similar research predicted a massive influx of visitors to the Yellowstone region when wolves were reintroduced, and though wildlife tour businesses have sprouted and are quite successful, overall visitation to Yellowstone has remained relatively constant since reintroduction (McMillion 2005). Additionally problematic, the survey questions make no mention of the potential negative effects of continued elk feeding, such as an increased chance of wildlife disease (Loomis and Caughlan 2004a). The model is based on a simple continuation of current trends, highlighting the costs associated with decreasing the animal populations

without addressing the negative effects of the feeding program. Because the survey ignores potential costs associated with the current management, the results are biased toward a continuation of the existing wildlife management paradigm.

The Integrated Social-Ecological System

A 1996 interagency plan and Environmental Assessment called for hunting of bison from the Jackson herd to control the population, which had discovered the feedlines on the National Elk Refuge and had begun taking advantage of the elk feedlines. In 1998, the Fund for Animals successfully sued the US government for failing to consider the refuge feeding program in the Environmental Assessment. As such, the National Park Service and the Fish and Wildlife Service are currently constructing an Environmental Impact Statement on bison and elk management to comply with NEPA requirements (Loomis and Caughlan 2004b). After several delays, a draft EIS is due out during the spring of 2005. Following a public comment period the final plan and EIS are expected by late 2006 (USFWS 2005). The Environmental Assessment described above was an interim decision, and the EIS process will determine the future of both the vaccination and the feeding programs (USFWS 2003b).

The vaccination issue has polarized local and regional stakeholders because of the plurality of demands on the elk, a common resource. Each group defines the problem in terms of their own needs, making many management decisions contentious. The recent lawsuits and vindictive arguments between the Wyoming Department of Fish and Game and the US Fish and Wildlife Service exemplify the diversity of views and values. Until the agencies agree upon a final management goal, scientists and managers will continue talking past one another and not address the different political structures that mandate their respective positions.

The Greater Yellowstone Ecosystem, and the elk in particular, are of great importance to local stakeholders for a variety of reasons. Figure 10 represents a conceptual model of the interconnections within the Jackson/NER social-ecological system. The

figure was created to aid in understanding system drivers and help select central uncertainties for the scenario analysis. As depicted in the figure, the local economy is highly dependent on elk, and the elk population is influenced by diverse factors. Changes in any of the system drivers, largely uncontrollable from within the system, could have direct effects on the elk population and thereby affect the local economy as well.

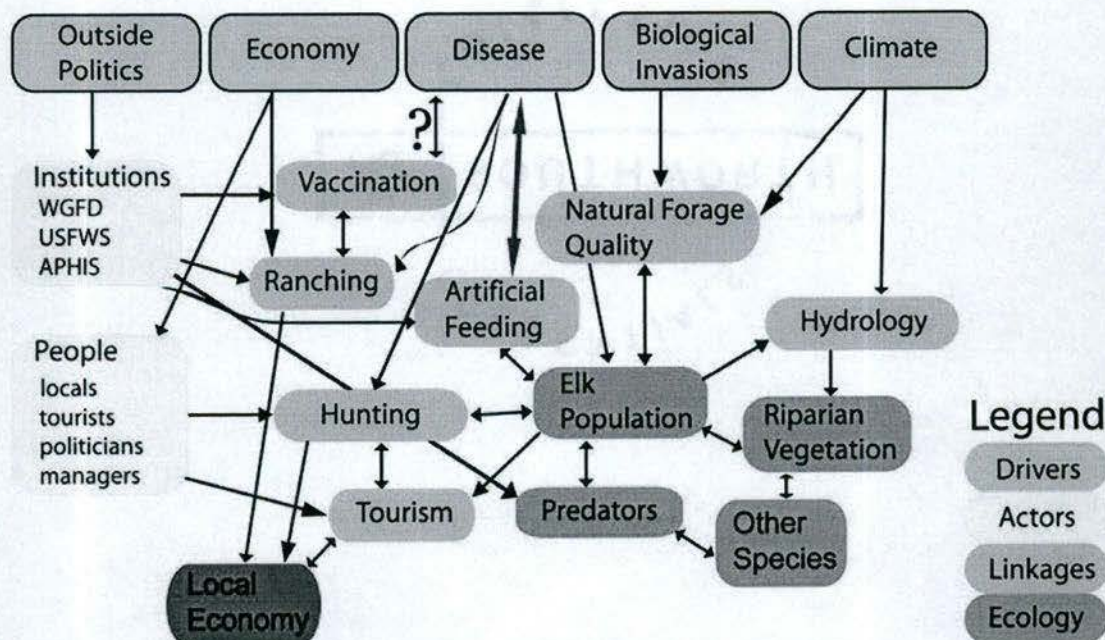


Figure 10 Map of interconnections in the Jackson/NER social-ecological system

The connections depicted here represent a mental model designed to aid in understanding system dynamics and potential drivers of change. As shown by the arrows, actors are unable to affect most of the system drivers. Disease, however, is influenced by the feeding program on the NER, and therefore can be somewhat influenced by management decisions. This diagram was created to assist in understanding system drivers and aid the selection of central uncertainties for the scenario analysis.

Uncertainties

The ecological system is currently optimized for elk production and the economic structure is dependent on a healthy, visible herd. The current management paradigm is a political compromise between diverse stakeholders with entrenched views. There is little chance for adaptive management to succeed in the area because of the entrenched views, periodic input of the court, and the ongoing NEPA analysis to decide on a management plan. The current large elk herd is part of a dynamic system, however, and is therefore

prone to sudden and unexpected change. This section explores two of many factors (depicted in Figure 10) that could potentially drive large changes in the social-ecological system: chronic wasting disease and wolf repopulation. These uncertainties are later used as central factors in a scenario analysis of potential futures for the social-ecological system.

Wildlife disease and the effects of wolves were selected to be central in the scenarios because of their controversial nature in the popular press, the recent attention they have received in scholarly journals, and the fact that they are only marginally controllable from within the system. Of all the uncertainties included in the scenarios, disease and wolf reintroduction are among the most controversial and the most plagued by disinformation. Many other uncertainties have the potential to affect the system and I do not intend my selection of these two factors to constitute a prediction that these two factors will be most influential in the future. The purpose of the scenarios is to highlight the potential for change and surprise, not to predict the type or cause of future changes.

This section is intended to provide necessary background information on the selected uncertainties and justify why their future effects on the system cannot accurately be predicted. The literature review was conducted in order to aid in developing a range of possible values for the selected uncertainties for use in the storylines. The scenarios are built around the uncertainties of wolf repopulation and disease in general, but because brucellosis was explored in the history of the system, attention here is focused on chronic wasting disease. The discussions of chronic wasting disease and wolves conclude with summaries of why the potential impact of each on the system is uncertain.

Chronic Wasting Disease

Introduction

Chronic Wasting Disease (CWD) is closely related to scrapie in sheep and goats, kuru and Creutzfeldt-Jakob disease in humans, bovine spongiform encephalopathy (BSE, a.k.a. mad cow disease) and its human counterpart variant Creutzfeldt-Jakob disease

(vCJD). The etiological agent of these diseases is likely a malformed glycoprotein, called a prion, which forms plaques in the brains of affected animals. Some researchers still question whether these diseases are caused by prions, or if the malformed proteins are an effect of a viral infection. For a summary of the arguments against the protein only hypothesis, see Farquhar et al. (1998). Between exposure to CWD and the onset of clinical symptoms there is an extended incubation period, the duration of which ranges from several months up to years. Symptoms, which are progressive, include: depression, listlessness, consumption of less food, excessive drinking and urination and a near total loss of stored fat. There are no vaccines or cures for CWD. Once contracted, the disease is invariably fatal (Williams and Miller 2002, Williams et al. 2002). This disease represents a potentially catastrophic disturbance to elk, deer, and the ecosystems of which they are a part.

Chronic wasting disease and the other aforementioned diseases are classified as transmissible spongiform encephalopathies (TSEs). Members of this family of diseases cause patterns of protein plaque buildup in brain tissues and vacuole formation in the brain. TSEs all have clinical symptoms similar to those listed above for CWD. Members of this class of diseases are contagious to differing degrees. CWD (Williams et al. 2002) and scrapie (Woolhouse et al. 1999) are capable of spreading via social contact and environmental contamination. BSE is less easily transmitted; it is only spread when cattle are fed rendered meat and bone meal. Variant CJD (vCJD), the human version of BSE, is spread in the same manner (Coulthart and Cashman 2001). Kuru spreads only via cannibalism (Mead et al. 2003), and the sporadic human prion disease, classic Creutzfeldt-Jakob disease (cCJD), can only spread by iatrogenic means (e.g. transplant and use of cadaver- derived hormones; Belay et al. 2001). CWD is the only TSE found in free-ranging animals (Williams et al. 2002).

History

Madson (1998) describes the early history of chronic wasting disease. CWD was first observed in 1967 at a Colorado Division of Wildlife animal research center in Fort Collins, Colorado. Deer in the research pens exhibited what are now recognized as CWD

symptoms, but at the time the disease was unknown. Because researchers did not understand the disease or its potential to spread, research facilities inadvertently increased the severity of the disturbance by regularly trading animals with one another. Within 10 years, the disease showed up at the Sybille research facility in southeastern Wyoming. In 1978 a researcher named Beth Williams made one of the first breakthroughs with chronic wasting. She discovered that the disease caused microscopic holes in the brain, creating a sponge-like appearance and classified it as a TSE (Williams and Young 1980).

Chronic wasting disease in the wild was first diagnosed in an elk from Rocky Mountain National Park in 1981 (Spraker 1998). The first infected free ranging deer was found near Fort Collins in 1984 (Spraker 1998). Though the initial cases of CWD were reported in the Fort Collins research facility, it is impossible to know for certain if the disease originated there. Although it is possible that the malformed prion thought to cause CWD arose spontaneously as a mutation of healthy prions (Williams et al. 2002), some suspect that CWD is the result of the transmission of sheep scrapie to deer and elk (Bartz et al. 1998). The first deer that died of what is suspected to have been CWD were confined in a pen with domestic sheep as part of an unrelated research study in Fort Collins, CO (Gerhardt and Hartman 2002). Gene Schoonveld, the researcher conducting the study, recalls that the deer "were in close proximity of the sheep for long periods of times (sic) and it was among those animals that the symptoms of CWD first showed up" (Gerhardt and Hartman 2002). Further evidence to support this theory is that people now recall that sheep in the facility at that time had scrapie, though there is no documentation to prove it (Gerhardt and Hartman 2002). Mathematical modeling has been done in an attempt to ascertain when CWD first appeared in deer and elk (Miller et al. 2000). The models suggest that free ranging deer in northeastern Colorado and southeastern Wyoming may have been affected since the early 1960's or earlier, but these predictions are not definitive because the transmission rates are unknown for this disease.

Human Assisted Spread

It has not been conclusively shown that humans were responsible for creating CWD, nor has it been proven that we are innocent of assisting that event; the initial case

may have been either a natural prion protein mutation, or a jump of scrapie to a new host made possible by the un-natural conditions inside the Fort Collins, CO research facility. Human ranching and management practices have without a doubt, however, contributed significantly to CWD's spread across the continent and overseas. Dr. Bruce Chesebro, a National Institute of Health researcher was recently quoted in a newspaper as saying: "People ask how this disease is spreading, and I say: 'by truck.' It is being moved around in these game farms [...] and it is leaking out into the wildlife. Until you close down the game farms, you can kill all the wildlife you want, and you will not halt the spread of this disease" (Herring 2002a). Without the game farming industry, spread of the disease would be limited by migration patterns. Game farms have hosted CWD outbreaks in far away places such as Saskatchewan and South Korea (Williams et al. 2002). It is clear that chronic wasting disease would not have made it to South Korea if not for shipping of infected animals.

Chronic wasting disease is endemic in a 38,137 km² area in southeastern Wyoming and northeastern Colorado (Miller et al. 2000). Approximately 60,000 mule deer and 15,000 elk occupy the endemic area (Gerhardt and Hartman 2002). Colorado, which is part of the endemic area, gives all authority over game farms to the Department of Agriculture; the Division of Wildlife has no authority over the industry despite the incredible effects game farms have on wildlife (Herring 2002b). Despite repeated requests by Mike Miller, a wildlife veterinarian with the Colorado Division of Wildlife, the Colorado Department of Agriculture still allows game farms within the CWD endemic area; there are currently 20 game farms there (Herring 2002a). CWD from wild animals can readily infect the game farms, and the farms regularly ship infected animals across the country or internationally. In one instance, seven different game farms in Colorado had to be quarantined because they were found to be infected with CWD. Nearly all of the infected elk were traced back to the Elk Echo ranch near Fort Collins, in the middle of the endemic area. Unfortunately, by the time officials traced the infected elk back to the Elk Echo ranch, more than 400 head of elk from that ranch had been shipped to 12 different states (Herring 2002a).

In 2002, CWD turned up in free-ranging herds in areas where it was little expected. In addition to cases in previously unreported areas on both sides of the continental divide in Colorado (Wasting disease pushes west, south into new territory 2002), a deer on the White Sands Missile Range in southern New Mexico was diagnosed with CWD (New Mexico mule deer tests positive for CWD 2002). Wisconsin identified CWD in both their domestic and free ranging cervids. In addition to being separated by a great distance from the endemic area, the Mississippi river separates Wisconsin from the endemic region as well. The source of this outbreak has not yet been determined. In April, 2005 the disease was reported in captive herds in New York, but it has not yet been observed in wild herds there (Chronic Wasting Disease Update 2005). Some of the outbreaks in wild animals are likely due to transmission from game ranches, but several cases remain unexplained (Williams et al. 2002). The White Sands Missile Range, for example, is far from any game ranches and the appearance of CWD in a deer there remains a mystery (New Mexico, 2002). The current ranges of the domestic and wild epidemics are shown in *Figure 11 The geographic range of CWD in captive and free-ranging cervids*. Chronic wasting disease has not yet entered the Greater Yellowstone Ecosystem, but it is approaching the ecosystem from the endemic area to the east.

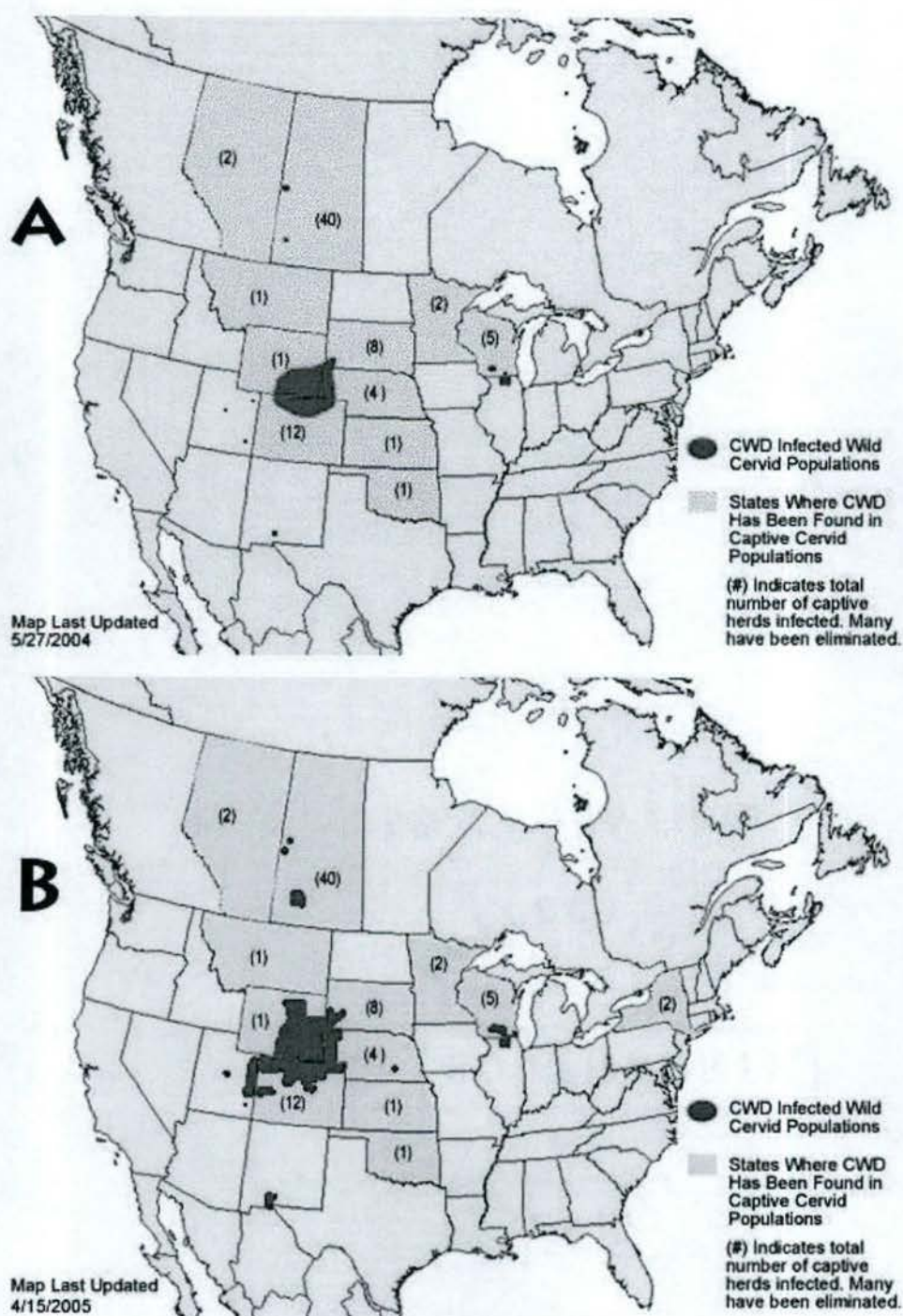


Figure 11 The geographic range of CWD in captive and free-ranging cervids

The range of CWD as of (A) 5/27/2004 and (B) 4/15/2005. The range increased in both captive and free-ranging herds.

Source: (A) Chronic Wasting Disease Alliance (2004); (B) Chronic Wasting Disease Alliance (2005)

Prevalence

Prevalence rates for confined animals can be frighteningly high. The elk in the Fort Collins research facility where CWD was first identified had a 36% infection rate in 1985 when the herd was killed (Miller et al. 1998). Of sixty-six mule deer and one black-tailed deer held in Colorado and Wyoming research facilities in the late 1970's, fifty-seven died of CWD (Madson 1998). One hundred forty-seven wild white tailed deer were confined next to an elk ranch in Nebraska. Forty-six percent of the first eighty-three animals tested from that herd were CWD positive (Tauschek 2002). In contrast, the highest infection rate for free-ranging animals is 15% among mule deer in Larimer County, Colorado (Miller et al. 2000). Prevalence rates in the endemic area of Wyoming and Colorado, obtained by random sampling, varied by geographic area and species. Rates for deer averaged 4.9%, whereas those for elk were much lower, around 0.5% (Miller et al. 2000). In general, prevalence rates tend to be higher for both mule deer and white-tailed deer than elk, and confined herds of all affected species suffer significantly higher prevalence than free-ranging herds.

Transmission

Prions are the putative infective agent for the transmissible spongiform encephalopathies. Researchers have long theorized that the disease is contagious through social contact between animals. Observations and research have shown that the diseased prions are remarkably stable in the environment. Taylor (2000) conducted a study to determine ways to destroy the infective agent in laboratory settings and found that they are exceedingly difficult to neutralize- even autoclaving fails to alleviate the infectious nature of the proteins.

Recent evidence suggests that at least some infections result from environmental contact with prions, even years after diseased animals have been in the area. Over the years researchers observed that animals introduced to pens where diseased ones were formerly

held spontaneously contracted the disease. At a research facility in Fort Collins, Colorado, researchers attempted a stringent disinfection process on a research pen:

All the deer and elk in the facility were killed and buried. Then personnel plowed up the soil in the pens in an effort to bury possible disease organisms and sprayed structures and pastures repeatedly with a strong disinfectant. A year later, they took twelve calves from the wild and released them in the sanitized holding areas. In the next five years, two of these elk died from chronic wasting disease. (Madson 1998)

Recent research with numerous experimental and control pens has shown that mule deer can contract the disease from areas contaminated with excrement and decomposed carcasses, even years after they had been inhabited by diseased animals (Miller et al. 2004).

Epidemiological Modeling

Gross and Miller (2001) constructed a computer model of the CWD epidemic mule deer in an attempt to understand the disease, its spread, and its potential consequences for wildlife herds. The results are disturbing. They were unable to find transmission rates that would allow for maintenance of CWD in their populations. Transmission rates sufficient to prevent the disappearance of CWD led to extinction of the modeled population.

Transmission rates are unknown in nature, but are obviously high enough to maintain the disease, as its range is spreading. This bodes ill for wildlife; transmission rates sufficient to maintain the disease (and it is maintained in wild herds) led to extinction of modeled herds.

The Gross & Miller model, however, oversimplifies CWD in several important ways. It likely underestimates actual disease transmissions because it assumes affected animals are not contagious until they show clinical symptoms (Gross and Miller 2001). Subsequent research, however, has shown that the diseased prion isoform accumulates in the alimentary tract prior to presentation of clinical symptoms. Researchers have concluded that shedding of the agent is likely progressive and begins prior to the onset of clinical symptoms (Williams et al. 2002). The model also fails to factor in environmental contamination and subsequent transmission, now recognized as likely sources of infection in actual herds (Miller et al. 2004). Additionally, the Gross and Miller model ignores density dependent changes in infection rate. As the populations are decimated, actual

contact events between animals are likely to occur less frequently simply because there are fewer animals (Schauber and Woolf 2003). These flaws, admitted by the authors to be oversimplifying, could seriously affect the accuracy of the model. The authors do not address the factor that perhaps most seriously weakens their model: genetic resistance to prion diseases.

Genetic Resistance to Prion Diseases

The prion gene is remarkably well conserved through all orders of placental mammals. The exact purpose of the gene remains unknown, though it likely plays a role in controlling apoptosis (van Rheede et al. 2003). Humans (Mead et al. 2003), sheep (Woolhouse et al. 1998), deer (Johnson et al. 2003) and elk (O'Rourke et al. 1999) each have polymorphic sections in that gene. The variations referenced in this chapter do not appear to change the native function of the protein, but do impart different degrees of resistance to prion diseases. This effect has been well studied for humans (kuru and CJD) and sheep (scrapie), and is beginning to be examined for elk and deer (CWD).

Resistance in Humans

Significant resources have been dedicated to the study of human prion diseases since 1995 when the first case of "Mad Cow Disease" in a human patient was identified. As it turns out, genetic resistance to prion disease is fairly important in humans. The main predictor of human susceptibility to prion disease is the status of codon 129 (either Methionine or Valine) in the gene encoding prions. The influence of this polymorphism appears to be quite strong, as all ninety-four confirmed and probable cases of variant Creutzfeldt-Jakob disease are homozygous for methionine at that codon, while that genotype amounts to only 37% of the overall UK population (Mead et al. 2003).

Kuru is a prion disease specific to people of the Fore linguistic group of Papua New Guinea. Sometime probably near the end of the 19th century people of this group initiated a tradition of consuming deceased relatives in cannibalistic funeral feasts. Kuru likely began when a victim of sporadic cCJD was consumed at one of these feasts. The disease spread rapidly through the population, at its peak claiming one percent of the population annually,

until cannibalism was outlawed in the 1950's. Despite its short duration, the kuru outbreak provided a strong selective pressure, favoring people with resistant genotypes (Mead et al. 2003). When Mead et al. (2003) genotyped a cohort of women over fifty who had participated in numerous funeral feasts, they discovered that twenty-three of the thirty were heterozygotes (the resistant genotype). Because women participated in the funeral feasts more often than men, they were more likely to be heterozygotes than a random sampling of the Fore population, in which fifty-five percent of the people exhibited the resistant genotype. Heterozygosity does not impart absolute immunity to kuru for people of the Fore linguistic group. It does, however, change disease progression: the mean age of onset for heterozygotes was over thirty, whereas it was nineteen years for homozygotes of either allele. Within a few generations, the resistant genotype was actively selected for and became over-represented in comparison to unexposed members of the Fore linguistic group. As a result, the group became more resistant to prion disease.

Resistance in Sheep

Sheep have polymorphisms in the gene encoding the prion protein, and like the polymorphisms in the human gene, the various sheep polymorphisms determine susceptibility to prion diseases. As discussed in Woolhouse et al. (1999), sheep have three common polymorphisms in the prion gene, with ten possible allelic combinations. In a study they conducted on a closed flock with scrapie, only sheep with two of the ten genotypes acquired scrapie. The authors of this study constructed a mathematical model of the scrapie outbreak in a domestic flock. As the flock is closed and the current genotypic composition of the flock is known, they were able to include genetic resistance in their model and evaluate its ability to predict current genetic composition. Their findings are shown in *Figure 12 Predicted genotypic frequencies in a modeled closed sheep flock affected by scrapie*. Over the course of a modeled scrapie outbreak, the resistant genotypes become less common, while the resistant genotypes increase in frequency. Their results agree qualitatively with the actual disease progression and the associated changes in allele frequencies within the flock, as well as with results from other flocks.

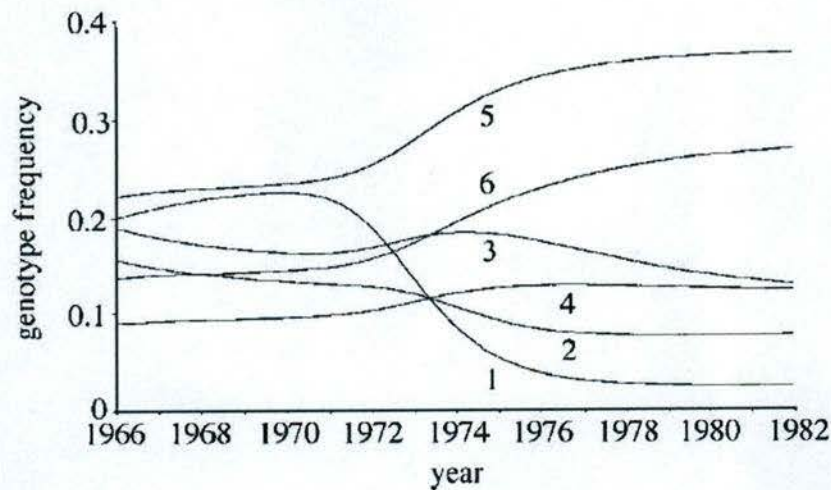


Figure 12 Predicted genotypic frequencies in a modeled closed sheep flock affected by scrapie

Genotype 1 is the most susceptible to scrapie, followed by type 2. Animals of the other genotypes are considered to not be susceptible to scrapie. As time progresses, the resistant genotypes make up an increasing proportion of the total. These model predictions resemble the actual dynamics of the modeled flock and observations of other populations.

Adapted from: Woolhouse et al. (1999)

Resistance in Elk

Elk also have a single amino acid polymorphism in their prion gene that, like polymorphisms in the human and sheep prion genes, determines how susceptible they are to prion diseases. O'Rourke et al. (1999) genotyped captive and free-ranging elk, including both CWD affected and naïve animals, and looked at the prion gene. What they found was that animals of one particular genotype (Met/Met homozygotes at the 132nd codon) were vastly over-represented among sick animals as compared with the rest of the population. In fact, all of the free-ranging elk they examined with chronic wasting disease were of that genotype (Met/Met homozygotes amounted to 75% of the non-affected animals examined). Heterozygosity at codon 132 does not impart absolute immunity to CWD; some farm raised Met/Leu heterozygotes in the study were affected by CWD. Met/Met homozygotes were over-represented in affected farm raised animals, however, confirming that Heterozygosity confers some level of resistance to CWD. It is important to note here that

codon 132 methionine homozygotes, the non-resistant genotype, made up a significant portion of the free-ranging elk in this study. If their findings are representative of free-ranging elk in general, most animals are of the CWD susceptible genotype.

Resistance in Deer

Mule deer have a polymorphism that could affect CWD susceptibility (studies have not been done), and white-tailed deer have two polymorphisms that do affect susceptibility. Currently, however, resistant genotypes make up a small fraction of the white-tailed deer population (4-14%) in Wisconsin (Johnson et al. 2003) and presumably elsewhere. Some affected deer were found to be of the more resistant genotype, showing that the resistant alleles do not confer absolute immunity. Based on in-vitro prion conversion experiments, the strength of the conferred immunity is likely not as strong as the genetic resistance conferred by resistant sheep prions to scrapie. The researchers in this study conclude that: "genetic resistance, based on changes in the prion protein, is not a viable option as a management tool" (Johnson et al. 2003). Their reasoning: the resistant genotype is rare and does not confer total immunity.

Resistance: Management Implications

The kuru outbreak in Papua New Guinea provides a case study on the selective pressures prion diseases put on affected populations. Despite not conferring absolute immunity to kuru, the resistant genotype increased in frequency within a few generations, making the population as a whole more resistant to the disease. Additionally, modeled sheep populations and trends observed in actual flocks indicate that alleles resistant to scrapie become significantly more prevalent when flocks are challenged by disease. Johnson et al., the authors of the study of genetic resistance in deer, may have prematurely dismissed the importance of that phenomenon. Resistant humans are not immune to kuru just as resistant deer are not immune to CWD. Nevertheless, the selective pressure was strong enough in the case of kuru to significantly change the relative allelic frequencies and make the population as a whole more resistant to the disease. I speculate that if mule deer populations adjust in a similar manner to human populations when challenged by prion

diseases, the increased deer herd resistance could result in CWD being naturally eliminated from the population. In modeled mule deer populations, even a slight reduction in transmission rates (10%) resulted in a three-fold greater chance that the disease would be eliminated from the population within fifty years (Gross and Miller 2001). There are no good models of the disease in elk, but as free-ranging elk harbor the disease at much lower rates than free-ranging deer and genetic resistance appears stronger in elk, it is possible that CWD could be eliminated from wild elk populations in the same manner.

The resistant alleles occur at a low frequency in both white-tailed deer and elk as compared to humans, but that could be due to a lack of previous pressure that would have selected for the resistant genotypes. Mead et al. (2003) speculate that the relative frequency of human alleles resistant to prion diseases could be the result of a pre-historic prion disease epidemic. I propose that CWD might provide an analogous pressure to select for resistant genotypes. Increased herd resistance could have profound effects on the course of the chronic wasting disease epidemic. It is possible that these populations could evolve sufficient resistance to eliminate the disease from wild herds. Again, the Gross and Miller (2001) study found that, in their models, a ten percent decrease in transmission rates drastically improved the chances that the disease would be eliminated from mule deer populations.

The Resistance Wild Card

Despite the long presence of scrapie in the United Kingdom, the non-resistant alleles are still relatively common in sheep flocks. Woolhouse et al. (1999) speculate that one possible reason would be multiple strains of scrapie, each primarily affecting one specific genotype. Sheep resistant to one strain could be susceptible to another. There are other possible explanations for the persistence of susceptible genotypes, and multiple strains of scrapie have not been identified. Similarly, some research suggests that there may be multiple strains of CWD (Race et al. 2002: , Johnson et al. 2003), which would drastically change the possibility of evolving resistance to the disease. As with scrapie, it has not been demonstrated that there are multiple strains of CWD.

Potential Transmission to Humans

The relative probability of a TSE affecting a species other than its usual host correlates with the homology of the protein sequences between the species (Raymond et al. 1997). BSE preferentially affects cattle, scrapie affects sheep and goats, and CJD and kuru affect humans. Most animals are experimentally susceptible to most forms of TSE when infective material is injected into their brains (Bartz et al. 1998). Obviously this situation does not occur in the wild; the technique's value is in ruling out possible transmission between sets of species. Interesting, however, is that the range of species susceptible to CWD injection can change when the disease is experimentally given to a new species. As shown in *Figure 13 Interspecies CWD transmission* summary, though hamsters are not susceptible to CWD from deer, they are susceptible to CWD from ferrets that were infected with deer CWD. Another interesting finding of this study is that the more times the disease was passaged in ferrets the more contagious it became to other members of that species. If the initial species barrier is overcome, the prions from diseased ferrets become more infective in subsequent transmissions within that species and the host range is altered once it switches to a new species. Some suggest that BSE originated from sheep scrapie and that a similar change in host range occurred when cattle contracted the disease: humans, which are not susceptible to scrapie, can contract BSE (Bartz et al. 1998).

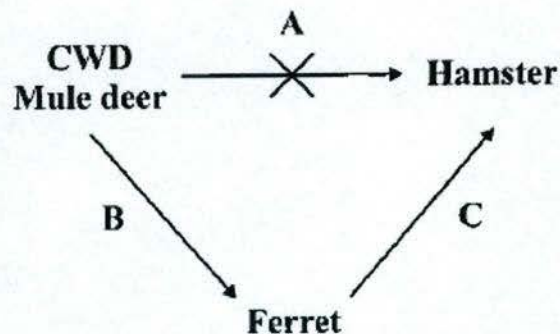


Figure 13 Interspecies CWD transmission summary

Mule deer CWD is unable to infect Syrian golden hamsters (A). Passage of mule deer CWD through ferrets (B) modifies tropism of the CWD agent, expanding the host range and allowing for infection of hamsters (C)

Source: (Bartz et al. 1998)

In vitro experiments have been done to test the efficiency with which diseased prions from one species can convert healthy prions from another to the diseased isoform. Early research showed that BSE (“mad cow”) prions were relatively inefficient at converting human prions to the diseased form (Raymond et al. 1997). Subsequent to that study, however, compelling evidence has shown that humans can in fact contract vCJD from cattle affected with BSE, implying that the species barrier was not insurmountable (Belay et al. 2004).

Raymond et al. (2000) performed similar research to investigate whether prions from affected deer can convert human prions. The researchers found that such conversions do occur, but there is a significant species barrier:

For cattle and humans, it is likely that susceptibility to CWD would be severely, but perhaps not completely, limited by the lack of conversion compatibility of the respective PrP [prion] isoforms. [...] Clearly, it is premature to draw firm conclusions about CWD passing naturally into humans, cattle and sheep, but the present results suggest that CWD transmissions to humans would be as limited by PrP [prion] incompatibility as transmissions of BSE or sheep scrapie to humans. (Raymond et al. 2000: 4429)

There has not been a demonstrated case of sheep scrapie being transmitted to humans, but humans are susceptible to BSE (Raymond et al. 2000). It is not yet known whether humans can contract CWD.

The Centers for Disease Control and Prevention have been monitoring cases of human prion diseases in an ongoing monitoring effort to determine if any are caused by the ingestion of CWD affected deer and elk. Sporadic prion disease does occur in humans, but usually late in life. Belay et al. (2004) reports a number of cases of human prion disease which attracted the attention of the CDC as potential examples of human CWD. Several were groups of unusually young men who died of prion disease and who also had ingested deer and elk. Epidemiological and genetic testing, however, led the researchers to conclude that the cases were due to sporadic prion disease rather than CWD. The researchers note that the incidence of human prion disease is not substantially higher in Colorado and Wyoming, areas where CWD has been endemic for decades, than in other areas of the country. There have been no documented cases of human CWD, but the authors suggest that it is too early to conclude that humans cannot contract the disease (Belay et al. 2004).

Current Management Practices

In desperate attempts to halt CWD's spread across the country, wildlife managers in Colorado (Williams et al. 2002) and Wisconsin are resorting to depopulating the areas around identified cases. Wisconsin, upon identifying three cases of CWD in a wild herd, planned to depopulate a 287 square mile zone with 15,000 deer (Nolen 2002). Williams et al. (2002) suggest that depopulation might not be the simple solution it may at first appear to be:

Although it seems intuitive that lowered deer and elk densities should reduce both transmission and likelihood of emigration by affected animals to adjacent areas, historic migration patterns and social behaviors characteristic of some deer and elk populations may diminish the effectiveness of wholesale density reduction in controlling CWD. (2002: 559)

Charles Southwick, a biologist concerned with the issue, believes there are two negative effects of the mass killings (Gerhardt and Hartman 2002). First, killing all the deer in an

area could inspire animals from an infected area to inhabit the newly empty area, spreading the range of the disease. Secondly, killing all of the animals around an infection means killing all of the animals that are genetically resistant to chronic wasting disease.

Chronic Wasting Disease as an Uncertainty

Mead et al. (2003) propose that at some point in human evolution, we, as a species, likely faced a prion disease pandemic. Their evidence: the alleles that confer resistance to prion diseases are more common than would be expected in the absence of such a pre-historic disturbance. The resistant alleles are less common in deer and elk populations than in humans, probably because they have never faced that challenge. In comparison to the proposed pre-historical human prion pandemic, CWD does not represent an unprecedented disturbance.

Humans have developed a stronger resistance to prion diseases than have deer and elk, but resistant alleles exist in both those species. Current models are overly simplified in that they do not account for this genetic resistance. In a worst-case scenario, chronic wasting disease could drive cervids to localized extirpation. Another possibility is that their populations might be severely diminished by CWD, but if they evolve resistance and their habitat remains, resistant animals could theoretically repopulate the herds. Also not entirely clear is whether humans are susceptible to CWD infection. Before CWD crosses the barrier (if it ever will) there is no way of knowing how infectious the disease will be amongst humans; CWD infectivity in ferrets increases with each transmission event within that species. Because CWD dynamics remain uncertain and long term evolutionary responses to the disease are unclear, predictions of the long term impacts of chronic wasting disease are uncertain at best. Equally unpredictable is how managers and government officials would respond were CWD ever to be discovered to be a threat to human health.

Wolves

Extirpation

The northern Yellowstone region provides an interesting case study for examining the effects of wolf extirpation because the region is well studied and much has been learned from their subsequent reintroduction to the region. The experiences in northern Yellowstone are worth studying because those same wolves are expanding their range into the southern part of the Greater Yellowstone Ecosystem, where Jackson is located.

Wolves were extirpated from Yellowstone National Park in the mid 1920s (Sellars 1997), substantially altering the ecosystem. "During the extended drought of the 1930s, some ungulate species, particularly elk, were considered to be 'overabundant' and 'range deterioration' became an issue" (Smith et al. 2003). A great deal of research was done in an attempt to discover a carrying capacity for the range at which the lands would not be overly degraded. As discussed earlier, the elk numbers were heavily controlled to try to keep the elk population down to a level that the managers believed was sustainable. In the 1960s the National Park Service adopted a more hands-off approach to park management, choosing to rely on natural regulation to control animal numbers. At the time, however, wolves were absent from the system and natural regulation meant mostly food limitation. The northern Yellowstone elk populations rebounded from around 4000 animals in the late 1960s to an average of 15,520 in the period from 1981-1982 to 1994-1995 (Smith et al. 2003).

Researchers began to realize that un-naturally large elk herds were affecting the vegetation structure and thereby altering the habitat for numerous other species (Kay 1997). Believers in the natural regulation approach held that limited food resources kept elk populations within a natural range. The deteriorated range conditions that were observed were in fact 'pristine' and natural (Kay 1997). The wolf extirpation had widespread effects throughout the ecosystem, some of which are only now being recognized as the system is readjusting to their presence.

Reintroduction

During the 1995-1996 winter, 31 gray wolves captured in Canada were released in Yellowstone National Park. Wolves recolonized much of the park and some adjacent areas in the Greater Yellowstone Ecosystem during the following seven years. As of the summer of 2002, there were at least 216 wolves in the Greater Yellowstone Ecosystem, with fourteen packs in (or mostly in) Yellowstone National Park and fourteen packs outside of the park (Smith et al. 2003). A map of the wolf territories within the Greater Yellowstone Ecosystem can be found in *Figure 14 2003 Greater Yellowstone Ecosystem wolf pack territories*.

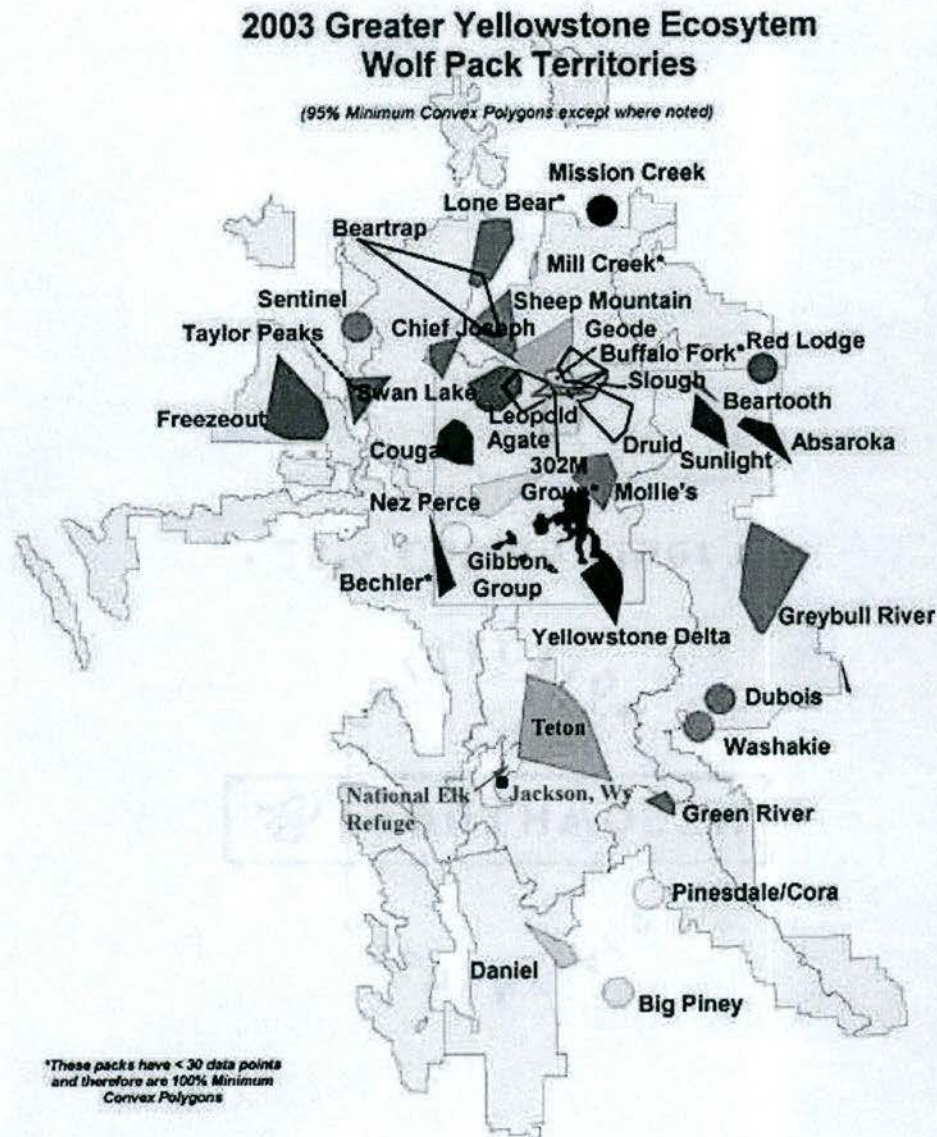


Figure 14 2003 Greater Yellowstone Ecosystem wolf pack territories

Adapted from: NPS (2003)

Elk constituted 92% of the 1582 wolf kills from 1995-2001. A disproportionate percentage of the wolf kills were calves, relative to the overall demographics of the herd. The adult cow elk killed by wolves were of a mean age of 14 years compared to a mean age of 6 years for hunter killed cow elk. Also, necropsies of wolf killed elk have shown that 34% of the elk killed have exhausted all of their fat reserves (Smith et al. 2003). Wolves are only one of a several predators that influence elk population dynamics,

including cougars, coyotes, and both grizzly and black bears. The reestablishment of wolf packs in northern Yellowstone has reorganized the ecosystem and had direct influences on the other predator species, potentially influencing their impacts on elk populations. Elk numbers in northern Yellowstone have been highly variable, both before and after wolf reintroduction (see *Figure 15 Elk population fluctuations and hunter harvests, 1965-2001*) and are dependant on a wide range of variables. The reintroduction of wolves has reorganized the predator structure which will likely have long-term impacts on elk populations (Smith et al. 2003).

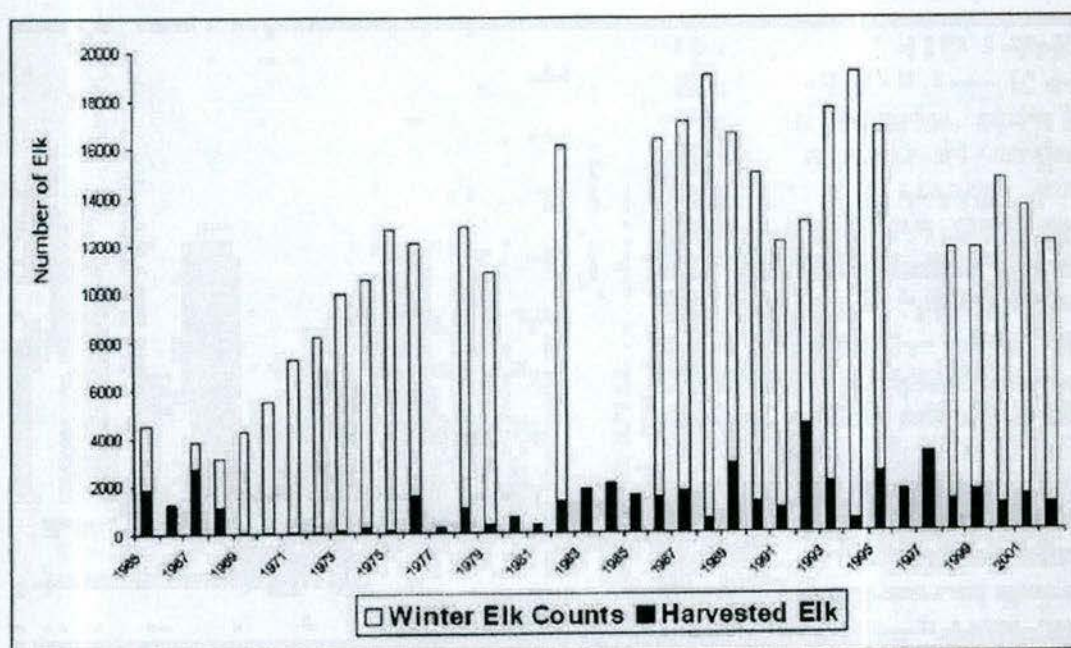


Figure 15 Elk population fluctuations and hunter harvests, 1965-2001

Source: Musiani and Paquet (2004)

The Greater Yellowstone Ecosystem is incredibly complex (see Figure 16 Complexity of the Yellowstone Ecosystem food web). Reintroduction of wolves, a top-level carnivore, had repercussions for the whole ecosystem. Changes in the behavior or population of numerous other species have been observed, including: coyotes, grizzly bears, cougars, ravens, eagles, and beaver. Changes are expected to occur in innumerable other species, though the full effects of the reintroduction are likely to take decades to fully develop (Smith et al. 2003).

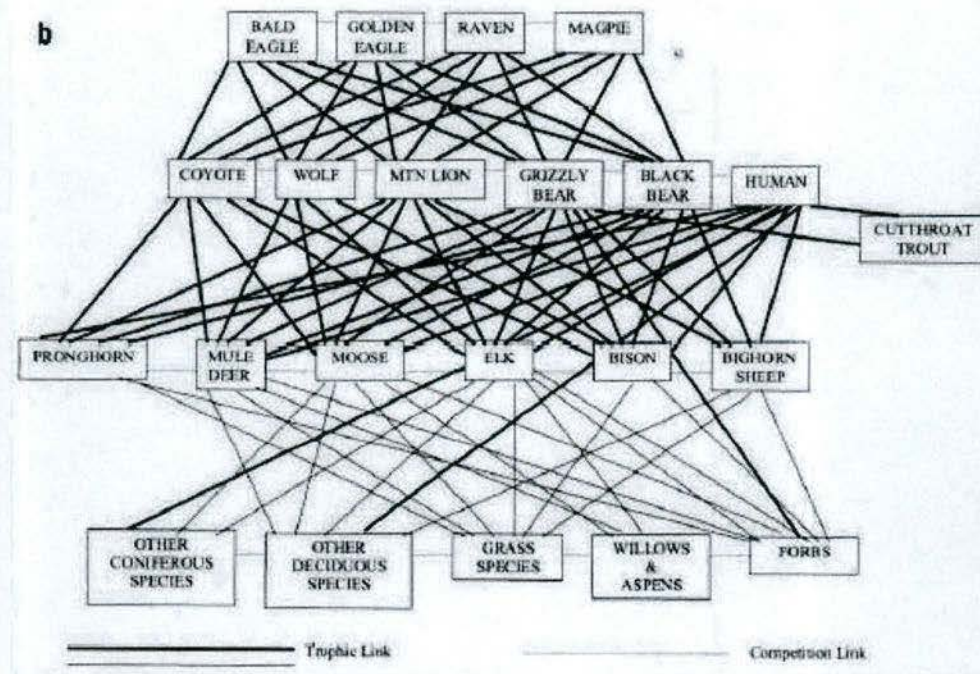


Figure 16 Complexity of the Yellowstone Ecosystem food web

Source: Smith et al. (2003)

The vegetation communities have undergone a reorganization following the wolf reintroduction. As noted above, the absence of wolves led to a drastic increase in the elk population. Compelling evidence has now shown that the increase in elk population and the changes in their browsing habits that attended the removal of the wolves effectively ended cottonwood recruitment (Beschta 2003, 2005). Similar effects have been observed in upland hardwood species such as willows and aspen (Ripple and Beschta 2005). All of these species are beginning to show signs of recovery with the wolves back in place. Changes in vegetation structure may have more to do with changes in elk behavior than with changes in their population; the presence of wolves seems to have changed elk browsing habits in ways that allow re-growth of riparian vegetation (Ripple and Beschta 2004). Along with the riparian vegetation, beavers have returned to areas inside the park where they had not been observed in the absence of wolves—a surprising effect considering wolves prey on beaver (Smith et al. 2003). The return of a top predator to the system has had numerous unanticipated effects on the ecosystem, and it is likely that some of the effects are yet to be observed. “From the complicated food web that exists in

Yellowstone [...] it is not hard to imagine that indirect effects of wolf recovery will be substantial" (Smith et al. 2003).

Wolves as an Uncertainty

Wolves are incredibly controversial animals: some people cite their reintroduction as one of the great conservation accomplishments of the century, whereas others are frightened that the wolves will eat all the elk and move on to livestock, pets and people (Smith et al. 2003). Prior to the reintroduction, many people were concerned that an overabundance of elk was doing damage to the range. "Already media attention has abruptly switched from concern about too many elk for the northern range to concern about too few elk for human hunters outside the park" (Smith et al. 2003). Some hunters and outfitters blame the wolves for ruining their businesses and depressing local economies (McMillion 2005). These types of concerns become a regional and national political debate involving state's rights issues, introducing another level of complexity to the social-ecological system. Also, if hunters hear that there are fewer elk, they are less likely to make hunting trips, an obvious hit to the economy. The 1994 Environmental Impact Statement for wolf reintroduction estimated that the reduced hunting opportunities would cause a loss to local economies of between \$207,000 and \$857,000 annually. Anecdotal stories from some outfitters confirm that there has been some effect on the hunting economy: some outfitters have noted that significantly fewer hunters are using the backcountry, both guided and unguided, and attribute the change to the presence of the wolves (McMillion 2005). It was predicted in the 1994 EIS that wolf related tourism would bring \$23 million to the local economy. A study was just begun to evaluate the actual economic impacts of the wolf reintroduction program (McMillion 2005).

As Smith et al. (2003) point out, there is a great deal of media attention around the average elk population size and the numbers of wolves in the system. The elk population is currently lower than immediately prior to the wolf reintroduction, but some of that reduction can be attributed to other causes such as the 1988 Yellowstone fires, drought, bears, and other sources (Smith et al. 2003, McMillion 2005). The predator-prey systems are highly dynamic, however, and are also affected by unpredictable surprises.

“Average population size is an interesting statistic, but no one should expect elk to spend any time there. At most times, they will either be increasing or decreasing, and at any given time wolves and elk will probably show opposite trends” (Smith et al. 2003: 333).

It could take years for the system to begin oscillating around the dynamic equilibrium (Smith et al. 2003). Even when the ecosystem starts to balance out, the complexity of the ecosystem makes it likely that it will be affected by surprise events.

Surprises, like the arrival of exotic disease [...] are virtually guaranteed in the long term, and they will assuredly influence, and possibly determine, the outcome of the great natural experiment in wolf—elk dynamics now launched at Yellowstone. (Smith et al. 2003: 339)

Wolf population dynamics are highly dependent on the nature of their interaction with human populations. “In North America, people have killed wolves for fur, for the protection of livestock and wild ungulates, for disease control, and out of fear” (Musiani and Paquet 2004). In addition to these direct influences, humans affect wolves and their ecosystems in numerous other ways, including hunting the prey species, development, and agriculture and forestry. Researchers have difficulty elucidating predator-prey dynamics in part because humans are so influential in wolf systems (Musiani and Paquet 2004).

The effects of wolves in the northern part of the ecosystem are beginning to play themselves out, but it is not yet clear what would happen were wolves to repopulate areas near the feedgrounds at the southern end of the ecosystem. There is currently a wolf pack in the vicinity, but animals from different herds have made appearances on the refuge on at least two separate occasions (Missing Wolves Spotted on Elk Refuge 2003). In the Lamar Valley at the northern end of Yellowstone, the presence of wolves in recent years has changed the spatial distribution of elk sufficiently to alter the vegetation structure there. Were wolves to become comfortable enough with the human population near the feedlines on the NER, the effect they might have on the elk there is unknown. Elk may not follow their instincts to flee when they are on feedlines, or perhaps they will make easy prey for the wolves. It is also possible that elk will become even more concentrated at the southern end of the refuge near the town of Jackson to avoid wolves in more remote areas. The presence of wolves near other feedgrounds has disrupted feeding programs (Dean et al.

2004); the same effect may occur on the NER were wolves to establish a more permanent presence—there is no way to know until that situation occurs.

CHAPTER V

THE SCENARIOS

These scenarios represent creative interpretations of potential futures for the Jackson/ National Elk Refuge social-ecological system. They are not meant to be predictions, but rather highlight unlikely events that could potentially cause drastic changes to the ecology or economy. They are meant to serve as tools to help spur discussion of uncertainties and system nonlinearities.

The storylines were created around two central variables: the effects on the system of wildlife disease and the re-establishment of wolf packs in the region. Chapter 3: Methods (page 37) describes the reasons why these two variables were selected to play a central role in the scenarios. The relative importance of the two variables in each scenario is summarized at the end of this chapter to allow readers to compare the storylines.

Scenario 1: Don't Sprawl on Me

Upon completing the 2006 Bison and Elk Plan EIS, the Fish and Wildlife Service decides to continue the elk feeding and vaccination programs that were in place in 2005. Brucellosis continued to be a problem as more cattle herds on the fringes of the Greater Yellowstone ecosystem were found to be affected by the disease. The Governor of Wyoming held an emergency meeting with representatives of the cattle industry throughout the region in an effort to ameliorate some of the fears of Wyoming cattle. Unfortunately, however, 2007 shipments of Wyoming cattle plummeted to just one quarter of the average from the previous five years.

Wyoming ranchers had been suffering from poor sales regionally and nationally around the same time when the US economy in general began to boom under a second dot com era. Largely unanticipated by many analysts, Google announced the release of an

operating system that successfully competed with both Microsoft and Macintosh systems. The increased competition spurred further software developments that included vast improvements in telecommuting capabilities. With the economy booming and companies relaxing their policies on telecommuting, millions of people from the cities began buying second homes throughout the west. Established resort communities like Jackson became more popular than ever. The years 2010 through 2015 saw a spate in development proposals throughout the private land in Teton County and the rest of the GYE. This development boom came just at the time when ranchers began dropping out of the business due to the fallout from the brucellosis epidemic. Most of the ranchlands in Teton County and neighboring counties were sold to land speculators and developers.

By the year 2025 there were approximately 75,000 people living in Teton County, Wyoming—about four times the population at the 2000 census. Most of the private lands within the county limits that were not protected under conservation easements had been developed. The process of developing those lands, however, proved divisive for the communities within Teton County. Ranchers were eager to develop or sell their lands when their livestock interests failed, but longtime residents and newcomers alike were upset to see the small town feel of their communities fall apart. They fought vigorously to prevent the developments, but one by one, the ranches were converted into suburban and exurban developments. Many of the old-timers began to abandon Jackson as the highways filled with cars and local restaurants were replaced with national chains. Rising home prices within the town of Jackson drove other long time residents to leave the community.

As Jackson grew in size and home prices increased, many service based employees moved to Teton County, Idaho, where the home prices also increased, but at a more modest rate. The daily commute over Teton pass took longer and longer as the traffic load increased. Despite the construction of additional lanes only a few years earlier, the commuting times over the pass were long enough that in 2017 Wyoming began lobbying Congress for funds to build a tunnel. The project was approved, angering residents of Wilson, Wyoming, where the tunnel was to enter Jackson Hole. Many residents who had

owned their homes for decades saw their quaint town turn into an industrial construction site for a decade as the tunnel was constructed.

Gradually, the connection between the Jackson economy and the ecosystem became more and more tenuous. Though tourism remained an important source for seasonal jobs, the abundance of telecommuters in the community meant that tourism jobs contributed a smaller percentage of the total jobs. Hunting and hunting access remained local priorities, but came to be more of a cherished hobby than an integral part of the economy and source of sustenance as it formerly was. Many of the outfitters who formerly benefited from the hunting economy were driven out by skyrocketing home prices. An increasing portion of the valley income came from telecommuting business people.

The elk that formerly wintered on some of the ranch lands found themselves in subdivisions and backyards. Some of the exurban developments had abundant grass and forage for the elk, but denser developments proved to be damaging to the local elk herds. Local conservation groups began programs to educate homeowners on wildlife-friendly landscaping. They had some success, but many of the new residents had dogs which effectively ruined the backyard habitat for ungulates. Some of the local residents feed the deer and elk in their backyards. Though this has long been a problem in Teton County, the loss of natural forage and a sense of guilt among some of the new homeowners increased the frequency of the practice. Unfortunately, cougars followed the deer and elk into people's backyards and there were increasing conflicts between pets and wildlife. Wildlife came to be seen as pests in peoples' yards and hazards to their pets.

The NER continued their feeding program throughout the first quarter of the 21st century, but the ecosystem was anything but stable. The continued high population of ungulates caused a gradual decline in riparian vegetation along Flat Creek and the Gros Ventre River, affecting the fishing quality there. With time, these formerly cherished trout streams lost their famed productivity. There was continual debate amongst refuge managers and conservationists about overgrazing of refuge lands, but most people realized the futility of trying to re-establish historical migration corridors; dense development precluded any hope of allowing elk passage through the Jackson bottleneck.

In 2011 wolves established a new pack in the hills just northeast of Jackson, in the foothills of the Gros Ventre Mountain Range. The pack gradually became more and more comfortable with people. As news of the pack spread, wildlife watching safaris became an increasingly important source of tourism dollars for the community. The wolves were surprisingly non-controversial as most ranchers had already been forced out of the area. People who were sick of seeing elk trample and devour their gardens saw the presence of the wolves as a healthy control on the elk population.

The winters of 2017-2018 and 2019-2020 were unusually wet and mild years. The elk had sufficient natural forage and were not fed during those winters. During the summer of 2020, however, the NER and Grand Teton National Park experienced a massive grasshopper invasion. Biologists estimated that only about 20% of the natural forage available most years remained when the elk arrived on the refuge. That same fall, the wolves became much more aggressive when the elk congregated on the feedlines. The elk herd moved quite often to avoid the wolves as a severe winter set in. Little natural forage was available for the herds and managers had a hard time delivering artificial feed to the continually moving herd. The winter of 2020-2021 saw a massive die-off of elk on the National Elk Refuge. It is estimated that 5,000 elk out of a total herd of 8,000 died before the snow melted.

Many local residents who previously saw elk as pests began to push for dramatic measures to protect the herd. Hunters, who had long been concerned that wolves were going to devastate the elk herds, felt that their fears had proved valid and pushed for the NER wolf pack to be killed. Wolf populations were heavily controlled regionally, however, and there were only 14 wolf packs in Wyoming, the legal minimum that the state had to maintain under their federally mandated wolf management plan. Within the confines of the wolf management plan, nothing could be done but relocate the wolves, which was tried in 2023. Within a couple of months, however, the relocated wolves were on the move again, and the following winter they arrived on the refuge again.

By 2025 the town of Jackson little resembled what it looked like only 20 years earlier. Despite an influx of people who considered themselves environmentalists, there

were increasing conflicts with wildlife. Few people who earned their money in the valley could afford to live there—a vast majority of the service employees, teachers, police and hospital employees had to commute from Idaho. The tunnel to bypass Teton pass was under construction, which dislocated many long-term Wilson residents. Though millions of tourists went through Jackson yearly, the town came to be thought of as little more than a roadblock on people's way to the national parks; it had lost its tourist charm and appeal. Jackson's economy had completely changed from one dependent on tourism to one directly connected with the computer technology industry.

Scenario 2: Who's Afraid of the Big Bad Wolf?

The July 12th, 2008 front cover of the New York Times read "Chronic Wasting Disease Hits Yellowstone." National attention focused on Yellowstone National Park following the headline. A tourist had hit and killed an elk with his car a month earlier at Fishing Bridge in central Yellowstone. When she reported the accident, park rangers went to the scene to remove the dead animal from the roadway and noticed its emaciated condition. As an extra precaution, the Park Service sent a brain sample to the University of Wyoming for testing. The result came back a few weeks later: the elk had late stage chronic wasting disease. This elk was the first identified case of CWD within the boundaries of the national park. In an attempt to assess the extent of the outbreak and limit further spread of the disease, several hundred elk in the vicinity of the index case were shot before the fall migration. All were tested, but none were found to have CWD. Following the identification of that first elk with CWD, all elk killed in the park were tested, including those that were killed by wolves. Four more cases were identified during 2008—all were wolf-killed elk.

The 2009 winter season passed with only one more case being identified—also a wolf killed elk. A policy was in place to test all dead elk in order to determine the extent of the outbreak, but no elk other than those killed by wolves tested positive. Researchers speculated that even before signs of infection are visible to human observers, affected elk

either lose speed, coordination, or are otherwise more susceptible in confrontations with wolves.

Though wolves gained respect in many peoples' eyes, they were not revered by all. A rancher in Sublette County, which borders Teton County on the southern side, claimed that wolves had killed twenty of his cattle. The carcasses he showed to investigators were too heavily scavenged to qualify for the Defenders of Wildlife compensation program because he could not conclusively show that they were actually killed by wolves. In order to be compensated for their loss by the nonprofit agency, ranchers had to be able to demonstrate that wolves killed the livestock rather than some other animal or other cause. But because the carcasses had already been picked clean by scavengers the cause of death could not be determined and the Defenders organization refused to compensate the Sublette County rancher. He then demanded that the federal government compensate him for his cattle or remove the wolves from the ecosystem. When the government did neither, the rancher set poison baits out for the wolves and killed three of them, including the alpha male and female. Sublette County passed a resolution in 2002 calling wolves socially and economically unacceptable—when the rancher killed the wolves, the county and a majority of Wyoming politicians supported him. The episode rekindled a national debate about the wolf reintroduction and local control over wildlife.

Though cases of CWD in elk were identified most years, the geographic distribution seemed not to spread any further. All of the identified cases were in the proximity of the index case, in central Yellowstone. Because the disease spread seemed to effectively stop in Yellowstone, hunting at the southern end of the ecosystem remained fairly constant throughout 2015. Heads from all hunter-killed elk were sent to labs for testing, but by 2010 most deer and elk hunters were accustomed to that practice.

When CWD was first identified in Yellowstone a number of concerned citizens launched a heightened campaign to end artificial feeding of elk in western Wyoming. The onset of a drought in 2015, which ended up lasting six years, caused advocates of that cause to change their minds. The winter of 2015-2016 was incredibly dry, with only about

30% of the average precipitation. The summer was a bit wetter than usual, but the following winter offered no respite from the drought.

Winter tourism suffered enormously when Jackson Hole Mountain Resort was unable to open for the 2015-2016 holiday season. The resort did manage to open for about a month, but even then only a few areas were ski-able. The following summer, tourism was down to about 65% of normal. The local economy felt the effects of the drought: seasonal employees left Jackson, hotels had large vacancies throughout the year, and businesses that directly depend on tourism dollars began to go under.

When the winter of 2020-2021 brought near record snowfalls, many thought their troubles were over. Hotels quickly filled when news of the consistent snowfall spread amongst skiers. The tourism industry rebounded somewhat at the beginning of the following summer as well. The moisture brought lush grasses back to the valley bottom and dense underbrush to many of the forested areas. Though winter moisture made for a lush green summer, little moisture fell over the summer. By fall, the grasses and forests had dried significantly, creating conditions that were prime for fires. A dry thunderstorm in late July started fires that quickly became uncontrollable. The conflagration was of a size not seen since the 1988 Yellowstone fires. In the end, significant portions of Grand Teton National Park, the Teton Wilderness, and the Gros Ventre wilderness had burned. When the fires started, tourism effectively ended for the season.

By 2025 the tourism industry had suffered significant losses. Many businesses stopped hiring seasonal employees, and some began laying off full time managers. A number of relatively well established businesses could not make ends meet and had to close their doors as a result of the drought. When the climate returned to normal, the tourism industry began to recover. It took several years, however, for Jackson and the national parks to regain their former reputation. Summer tourism remained low for several years due to the extensive burn area.

Ecologically, the effects of the drought were quite varied. The northern Yellowstone elk, which were not fed, did not fare well. Following the decrease in the northern elk herd, the wolves that relied on those elk also decreased in number. Many

wolves wandered during that time in search of food. Some were illegally shot and poisoned when they left the protection of the parks; others were killed when they resorted to livestock depredation, further fueling the ongoing controversy. The Jackson elk herd fared better because of the artificial feeding programs at the southern end of the ecosystem. Wildlife officials attempted to feed the elk as little as possible so as to minimize the potential for CWD transmission, resulting in some winter starvation. Though elk numbers suffered some, the relatively large elk population on the National Elk Refuge did incredible damage to the grassland communities during the course of the drought. Very little natural grass grew during the dry years, turning the southern end of the refuge where the elk spend significant time into a dust bowl. Managers seeded much of the refuge with native grasses when moisture began returning to the valley, but much of the original diversity was lost and invasive species gained a foothold.

Scenario 3: Cattle Ranchers vs. Wyoming Game and Fish Department

Just as some biologists feared, CWD continued its march westward until it reached Yellowstone National Park in 2008. Though the outbreak made front page news nationwide, much of the public was accustomed to hearing reports of CWD spreading. Park managers killed several hundred elk in order to determine the extent of the outbreak. The results from those tests combined with ongoing testing of all deer and elk that die in the park (from collisions and natural causes) led researchers to conclude that the disease occurred at a relatively low prevalence. Initially, only about 1% of deer and around the same percentage of elk was affected.

Tourism to Jackson and the national parks was not affected by the initial news, but outfitters estimated that they lost hundreds of thousands of dollars of business in 2009 and 2010 due to cancellations and decreased reservations. Hunters and outfitters in the region were divided over what should be done to protect the western Wyoming elk herds from infection. Some wanted more drastic measures taken to reduce the chances of a large-scale outbreak, including a phasing out of the feeding program and herd reduction. Others were

relatively unconcerned, citing the long history of infection and low prevalence rates among elk at Rocky Mountain National Park.

The politics of elk management became more divisive then ever when CWD was identified amongst elk in the Jackson herd on their summer range. A coalition of conservation organizations and hunting groups began petitioning for an emergency reduction of the feeding program. Other hunting groups joined with ranching groups in arguing that sudden changes to the elk management strategy would cause more problems than it would solve. The coalition that favored an emergency herd reduction filed a lawsuit to force the Fish and Wildlife Service to make changes to their management strategy. The ranching coalition filed as interveners on behalf of the FWS, the defendant.

In an expedited decision, a US District Court judge found that the Fish and Wildlife Service had decision making authority, but suggested that the federal agency consider taking a more aggressive approach to controlling the outbreak because of the financial importance of the western Wyoming elk to the local economies.

Recognizing that an outbreak of CWD could devastate the dense elk herds on the National Elk Refuge, the US Fish and Wildlife service began decreasing the amount of food it made available to elk on the NER each winter. A massive herd reduction program was put into place for three years to bring the herd down to what was believed to be the natural carrying capacity of the remaining winter range. Because of the national press coverage that CWD had been receiving, there were not enough hunters available for the number of elk that needed to be killed in order to bring the elk population down to numbers that managers calculated the range could support without artificial feeding. To fill the void, Park Service rangers were brought in to kill hundreds of elk. Bison numbers had to be artificially reduced as well, because although they cannot contract the disease, elk were commingling with bison on their feedlines. All of the elk killed were tested for CWD, revealing that the elk on the refuge suffered a prevalence rate of around one percent—similar to the rate for free ranging herds in Rocky Mountain National Park.

The goal of the herd reduction was to bring the size down to what the available winter range would support. The elk that remained on the refuge were dispersed over the

entire remaining range. The ranching industry began to push for more intense management of the elk herds to prevent intermingling between elk and their livestock. They advocated for reinstatement of the feeding in order to keep the elk from commingling with cattle on livestock feedlines. It has not been shown that cattle can contract chronic wasting disease, but following Wyoming's loss of brucellosis-free status in 2004, local ranchers have been eager to demonstrate to regional and national regulators that their herds are well protected from wildlife disease. Ranchers were beginning to feel pressure from regional cattle buyers who were reluctant to purchase Wyoming cattle because of the negative associations consumers have with prion diseases.

During the summer of 2017, about twenty percent fewer visitors came to Grand Teton and Yellowstone National parks as a result of the reduced elk herds and the negative publicity surrounding the CWD outbreak. The situation became drastically worse when a series of articles in national newspapers brought the elk of the refuge to the national spotlight. Horse-drawn sleigh rides through the refuge were cancelled in 2019 due to a lack of animals in the area. A reporter vacationing in Jackson at the time took photos of elk dying of starvation along the fence that separates the highway from the refuge. It wasn't clear from the story whether the elk was dying of starvation or chronic wasting disease, as both were featured in the article.

Another court battle erupted when elk at a state-run feedground were found to harbor CWD at significantly higher prevalence rates. The state maintained their feeding program to try to minimize wildlife depredation on livestock feedlines and minimize commingling with cattle. Hunting and wildlife groups sued the state to limit the feeding program but were unsuccessful. There was continued bitterness between the state government, the FWS and local stakeholder groups over wildlife and disease management.

When a diseased elk was seen commingling with cattle on a livestock feedline, the rancher sued the state claiming that they were negligent in their wildlife management practices. When he successfully sued the state for damages associated with the reduced marketability of his cattle, Wyoming wildlife managers began to search for a management strategy that would prevent elk from commingling with cattle, yet not artificially

concentrate the elk any more than they already were. The state offered to install fences around ranches in areas where CWD was endemic in the wildlife herds, but that did nothing to address the innumerable grazing allotments that spread throughout the state.

In a compromise agreement, the Wyoming Game and Fish Department agreed to a massive herd reduction policy that reduced the total elk population in western Wyoming by around 50%. Ranchers were given the additional authority to shoot any elk on sight that was intermingling with livestock. The feedgrounds in western Wyoming were left in place to keep the remaining elk from wandering onto cattle feedlines. The Wyoming Game and Fish Department was forced to go to the state legislature for additional funds for wildlife control when they were suddenly burdened with additional responsibilities at the same time that their income from the sale of hunting licenses effectively ended.

The total dollars that tourism brought to the economy stayed about twenty percent below normal, and the hunting economy pretty much ended statewide. Each fall park rangers and game wardens had to shoot elk to keep the population at the predetermined population levels. In 2025 the Jackson/ National Elk Refuge social-ecological system seemed to be settling into a new state. Tourism and hunting money were down and the ranching industry continued to have problems marketing their cattle for interstate shipping. The Chamber of Commerce began playing up the community's other strengths, such as its unique western character and small town feel. Chronic wasting disease was becoming old news, as it had spread across most of the nation. The disease ceased making national headlines and hunting actually was beginning to recover nationwide. In western Wyoming, however, the elk population was so low that hunting became an insignificant part of the economy.

Scenario 4: Mad Elk Disease: Coming to a Theater Near You

It was not a great surprise when chronic wasting disease was identified in deer in Yellowstone National Park; the disease had been spreading in that direction for years. The far greater surprise was when researchers with the Centers for Disease Control and

Prevention in Atlanta announced that they believed humans are susceptible to infection with CWD. In a nationwide epidemiological study, they found statistically significant increases in occurrences of Creutzfeldt-Jakob Disease (CJD) amongst people who regularly consumed venison and elk. As of 2010, however, they had not identified any individual cases that they could identify as specifically due to ingestion of meat from CWD affected animals. The report concluded that the human form of CWD might be symptomatically and histologically indistinguishable from sporadic CJD, a human prion disease that occurs randomly amongst older patients.

Subsequent reports questioned the methods and data sources of the initial publication, but did little to quell the public fear of the disease. The case was closed when a twelve year old boy whose family consumed venison nightly died of CJD. A natural case of sporadic CJD is unheard-of in patients of that age. Autopsy and intensive histological investigation revealed subtle morphological differences between sporadic CJD and human CWD. Samples from the past several years worth of human prion disease victims revealed that a relatively small number of cases were attributable to CWD, but that did little to calm the fire in the press.

A series of stories in the popular press covered the research on CWD to date and what was known about transmission in animals. When a front-page article in Newsweek questioned "Can CWD be spread via social contact in humans?" true panic ensued. Researchers reassured the public that they had absolutely no evidence that CWD could spread between humans but stories questioning the research continued to make front page headlines. Massive wildlife "control" programs were created to wipe out deer and elk near population centers. Informal groups of hunters roamed open lands throughout the country shooting all deer and elk in sight.

A number of congressional representatives began to argue for the wholesale slaughter of ungulates in the national parks, arguing that they were reservoirs of CWD infection. In a hard fought compromise, the animals were not slaughtered, but the parks were closed until further research determined the true risk to humans. Deer and elk were shot by state wildlife officials and members of the public when they moved beyond the

park borders. Jackson became a front-line in the battle to keep ungulates away from people. Several layers of fences were built along the edges of the refuge to keep the animals out of town. As might be expected, tourism to this formerly booming resort town virtually stopped. The elk program was abruptly stopped, leading to large scale elk starvation over the first several winters. The deceased elk were bulldozed into piles and burned to remove any prions from the environment.

In 2018, after about eight years of ungulate eradication programs, it was shown conclusively that CWD is only minimally contagious to humans. Infection requires significant ingestion of meat from affected animals and only about 35% of the population is susceptible to disease. CWD was discovered to not be contagious between humans, and people cannot contract the disease from environmental contamination, the way the disease spreads amongst ungulates. The panic gradually waned and the national parks were once again opened to visitation.

Ecologically, the CWD panic was truly destructive. The only significant populations of deer and elk that remained in 2025 were those in the national parks. Managers nationwide faced a catch-22; ecosystems were dramatically different in the absence of deer and elk, but feeding programs which would encourage growth of the remaining populations were considered out of the question due to the increased incidence of CWD amongst dense herds of ungulates.

Tourism to the Greater Yellowstone Ecosystem gradually recovered as the CWD panic abated. Locals hoped that the national parks would regain their status as national treasures of ecological diversity. As might be expected, there was some pressure to once again remove wolves from the ecosystem in order to maximize recruitment of deer and elk. Though the CDC estimated they expected the human CWD outbreak to be limited to around 200 victims, nationwide hunting of ungulates for food effectively ceased. Poaching limited the recovery of ungulate populations as many considered them to be dangerous pests in the wake of the CWD epidemic.

Summary of the Scenarios

The scenarios presented in this thesis represent various potential futures for the Jackson, Wyoming/ National Elk Refuge social-ecological system. They are constructed by assembling plausible values for a number of key uncertainties that could shape the future development of the system. A more complete description of how the storylines were constructed is available [Chapter 3: Methods](#) (page 37). Table 1 *Comparison of the scenarios* is a side by side comparison of the factors that were influential in the various storylines and memorable outcomes in each.

The storylines emphasize the dynamic nature of the ecosystem, the social system, and the combined social-ecological system. The plots described in the scenarios are not predictions of future conditions, but rather plausible storylines that combine factors currently known to have the potential to drive change in the region. Drivers of change interact in a variety of ways in each of the scenarios. In the “Don’t Sprawl on Me” storyline, for example, changes to the national economy interact synergistically with local ecological and economic issues in ways that result in a spate of development in the Jackson Hole valley. Not all surprises, however, destabilize the system. In “Who’s Afraid of the Big Bad Wolf?” interactions between system drivers serve to cancel each other out—wolves turn out to be a barrier against further spread of CWD. The wolf-CWD dynamic is not intended as a prediction, but rather represents a possible effect which has not received much attention in discussion of either disease progression or wolf reestablishment.

Though wildlife diseases and the effects of wolves were selected as the central uncertainties, the scenarios reflect the variability of other system drivers such as climate, fire patterns, external economics and insect populations. Variability in these other factors was included in order to flesh out the scenarios and allow them to reflect a wider range of potential futures.

The fourth scenario is a wild card, designed to highlight the fact that little is known about CWD’s potential to spread beyond deer and elk. As explained in the literature review of scenario analysis, authors suggest that extreme elements should be included in storylines because the “... intent of scenarios is not to predict the future but to improve

abilities to adapt to it" (Wollenberg et al. 2000: 71). None of the events included in the various scenarios (e.g., drought, fire, insect invasion, large effects of wolf repopulation, and humans being discovered to be susceptible to CWD) are likely in any given year (and therefore may be considered 'extreme,') but none are impossible given the current knowledge of the system. Including in the storylines events such as these, which might be considered extreme, helps readers to understand that the future could actually be affected by one of those unpredictable happenings.

Table 1 Comparison of the scenarios

		Scenario Title			
		#1 Don't Sprawl on Me	# 2 Who's Afraid of the Big Bad Wolf?	# 3 Cattle Ranchers vs. Wyoming Game and Fish Department	# 4 Mad Elk Disease: Coming to a Theater Near You
Summary of effects	Wildlife Disease	• Brucellosis in cattle	• Chronic wasting disease in Yellowstone	• Chronic wasting disease amongst Jackson Herd elk ◦ Reduction in elk feeding ◦ Elk & bison herd reduction	• Chronic wasting disease is discovered to be transmissible to humans • The disease is found in Northern Yellowstone and Jackson herd elk
	Wolf repopulation	• Wolves enter area, eventually preventing elk from using feedground	• Yellowstone wolves limit spread of CWD • Wolves heavily depredate cattle in Sublette County	• No effect	• Little effect
	Other Variables	• Dot.com resurgence ◦ Economic boom ◦ Telecommuters • Grasshopper invasion	• 6 year drought • Fire	• No effect	• No effect
	Notable Outcomes	• Decline in ranching • Development spate • Tunnel to Idaho • Elk starvation die-off	• Drought hurts both summer and winter tourism • Fire deals another blow to tourism industry • Extensive drought/elk damage to refuge rangeland • Wolves effectively limit CWD spread	• Tourism decline • Hunters/ environmentalists sue state for continued feeding despite CWD outbreak • Ranchers sue WDFG when CWD elk leave feedgrounds • Massive herd reduction	• Ungulate eradication nationwide • Temporary closure of national parks • Nationwide reorganization of ecosystems as ungulates were nearly eradicated during disease panic

CHAPTER VI

CONCLUSION

In the monocropped field and single-species forest alike, the innumerable other members of the biotic community were ignored unless they had some direct bearing on the health and yield of the species to be harvested. Such narrowing of attention to a single outcome—invariably the one of most commercial or fiscal interest—confers an analytical power that allows foresters and agronomists to track carefully the influence of other factors on this single dependent variable. Within its ambit, there is no denying the extraordinary power of this approach to increase yields. As we shall see, however, this potent but narrow perspective is troubled both by certain inevitable blind spots and by phenomena that lie outside its restricted field of vision. To continue this metaphor, the narrowness in turn means that production agronomy is occasionally blindsighted by factors outside its analytical focus and is forced, by the resulting crisis, to take a broader perspective. (Scott 1998: 263)

Though artificially feeding elk has never been an explicit purpose of the National Elk Refuge, the charismatic mega-fauna have been fed there for all but a few years since the refuge's inception. The animals are fed to prevent unsightly and unpopular winter die-off events and to provide a large and visible elk herd for the diverse stakeholders that rely in one way or another on them. The elk are a beloved species for hunters, tourists, and distant sympathizers. To local ranchers, elk represent the last natural reservoir of *Brucella abortus*, a bacterial species that causes infected elk, cattle, and bison to abort their first fetus following infection. Ranchers in the state of Wyoming hold brucellosis to be a threat to their economic viability and have to demonstrate to out-of-state buyers that they are doing all they can to combat the disease. The state of Wyoming recently sued the federal government for the right to vaccinate elk on the refuge with a brucellosis vaccine designed for use in cattle and which may or may not be effective in elk. I argue that vaccination is an effort to convince ranching interests that they are taking active steps to eradicate the disease and for that purpose it matters more that the animals are vaccinated than that the

vaccine works. The evidence suggests that the only way to eradicate the disease would be to stop feeding them, an act that would likely increase the intermingling of wildlife with livestock. The current management regime represents an attempt to optimize the system for a diverse set of stakeholder needs. The feeding program, however, artificially concentrates the elk and creates conditions that are ideal for the spread of disease. The current stability of the system is an artificial one, and the current attempt to optimize the system may in fact make it more vulnerable to change.

The storylines in this thesis use plausible (though sometimes extreme) values for potential system drivers to demonstrate that the Jackson, Wyoming/ National Elk Refuge social-ecological system is dynamic and can change in sudden and unexpected ways based on factors uncontrollable from within the system. The current ungulate-centric management focus provides diverse stakeholders with abundant elk based on the current conditions, but undermines the resilience of the social-ecological system. Any changes to the elk herd, whether from disease, wolf dynamics, grasshopper invasion, drought, fire, or any other cause, have the potential to upset the local economy. Future decisions regarding National Elk Refuge management need to acknowledge the potential for the system to change. By being aware that the system is dynamic and looking forward to possible drivers of change, managers can create plans that are robust to a variety of futures. Such plans can help to maintain the system in a desirable state whereas those that continue to optimize it for a single ecosystem product further undermine system resilience.

Science cannot prove that chronic wasting disease will or will not reach the elk in the Greater Yellowstone Ecosystem. Science cannot prove that wolves will or will not begin to predate on the elk on the feedlines on the National Elk Refuge and similarly cannot determine how the elk will respond. Ecosystem dynamics are complex and while we have learned a great deal by observing both CWD's spread and wolves in their re-established territories, ecology cannot accurately predict the effect either of these variables will have on the Jackson, Wyoming/ National Elk Refuge social-ecological system. We have an incomplete understanding of how the system currently works and we cannot predict extrinsic surprise or internal thresholds that could destabilize the system.

Ecological changes can have social repercussions. As described in this thesis, the Jackson, Wyoming economy is intimately tied to the ecosystem through tourism, ranching, and hunting among other mechanisms. Chronic wasting disease has the potential to reorganize the nature of the relationship between the Jackson economy and the local elk herds, and in fact could fundamentally alter perceptions of nature nationwide. Experiments to date have shown that there is a species barrier that limits the likelihood that CWD will be transmitted to humans, but a similar barrier is crossed each time a human contracts bovine spongiform encephalopathy (commonly known as Mad Cow Disease). Were humans discovered to be susceptible to chronic wasting disease, people might begin to consider deer and elk to be disease vectors rather than charismatic mega-fauna. Current research suggests that chronic wasting disease outbreaks amongst confined deer and elk are much more severe than those amongst free-ranging animals. Smith (Smith 2001) suggests that feeding elk on the National Elk Refuge could exacerbate the severity of disease outbreaks there. Planners need to consider the possibility for wildlife diseases to affect humans when evaluating current management regimes.

Adaptive management is a powerful tool for ecosystem planning, but is of little use when plans are political compromises rather than forward-thinking ecological management plans. Under adaptive management, management regimes change to incorporate the latest knowledge gained through past management experiences. As explained in Chapter 4: Analysis of the Jackson, Wyoming/ National Elk Refuge (page 40), however, intense political negotiations and legal compromises have defined the current management of the National Elk Refuge. With such entrenched positions, stakeholders are unlikely to accept changes to the management regime without additional lawsuits and political struggles. This scenario analysis is intended as an accessible tool to help stakeholders understand that the social-ecological system is dynamic and will continue to be so.

By utilizing a scenario analysis approach, decision makers can take potential driver into account without a definitive answer from scientists about what the future holds. Failing to plan for an arrival of chronic wasting disease, for example, could have significant ecological and social costs. Plans for the future that are based on a continuation of current

trends are vulnerable to the surprise that is inherent within any complex system. Scenarios created during a scenario analysis can be used to evaluate current plans in terms of a range of futures, which can be beneficial even if the future is not accurately depicted by one of the storylines. Occasionally a system is disrupted by a surprise of such large proportion that it causes a fundamental reorganization of the system. Similarly, incremental change can cause reorganization of a system when a threshold is reached. Managing a system for resilience (i.e., making plans robust to a variety of possible futures) requires buy-in from all of the stakeholders because a system managed for resilience is not managed for optimal production of any one ecosystem good or service.

The Jackson, Wyoming/ National Elk Refuge social-ecological system is internally complex and is influenced by a number of extrinsic social and ecological drivers. Though the future of the system cannot be predicted by science, managers can use the existing scientific and social knowledge to make plans that acknowledge uncertainty and the propensity for surprise to drive system dynamics. Though it has not yet affected the system, chronic wasting disease is approaching from its endemic area to the northeast. The current management of elk on the refuge is predicated on a continuation of current trends within the system, but fails to address the possibility that CWD will continue in its westward expansion. This thesis is a preliminary scenario analysis of the Jackson, Wyoming/ National Elk Refuge social-ecological system designed to remind readers of the dynamic nature of the system. Scenario planning is an iterative process and I encourage others to perform similar analyses to address other potential drivers of change for the region.

APPENDIX A

LIST OF ACRONYMS USED

APHIS	Animal and Plant Health Inspection Service
BSE	Bovine Spongiform Encephalopathy
cCJD	Classic Creutzfeldt-Jakob Disease
CJD	Creutzfeldt-Jakob Disease
CWD	Chronic Wasting Disease
EIS	Environmental Impact Assessment
GYE	Greater Yellowstone Ecosystem
NEPA	National Environmental Policy Act
NER	National Elk Refuge
NGO	Non-Governmental Organization
NWRS	National Wildlife Refuge System
SES	Social-Ecological System
TSE	Transmissible Spongiform Encephalopathy
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
vCJD	variant Creutzfeldt-Jakob Disease
WDGF	Wyoming Game and Fish Department

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